Division of Agricultural Sciences
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SOYBEAN RESEARCH IN CALIFORNIA

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(Editors)

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Soybean yield and other data from small plot and field-size experiments in California have been included in annual reports of various research organizations for over 50 years. However, these data are not generally available to the public. Even though there has been no sustained commercial production of soybeans in California, there is a continuing interest in the crop by farmers, oil mill processors, and consumer organizations. This bulletin summarizes the results of various soybean experiments in California and compares these results with data from other areas where the crop has been profitable to producers.

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WARNING

University of California recommendations for pest control are based on the best information currently available. Treatments described in this bulletin are for information only and do not constitute a recommendation for use in commercial plantings. Treatments should give control without leaving residues that will exceed the tolerance established for any particular chemical. Because this crop is not commonly grown in California, tolerances have not been established. Before you treat for control, consult the latest U.C. Pest Control guide, your local Farm Advisor, or the local State Agricultural Commissioner for up-to-date recommendations.

The grower is legally responsible for residues on his crops as well as for problems caused by drift from his property to other properties or crops.

SOYBEAN RESEARCH IN CALIFORNIA[1]

INTRODUCTION

B. H. Beard, M. D. Miller, P. F. Knowles

Because of its great usefulness, the soybean became one of the five sacred crops of China, along with rice, wheat, common millet, and glutinous millet. Soybeans were introduced to neighboring countries probably during the early years of the Christian period. It is very likely that soybeans will provide an important part of the protein (as well as the vegetable oil) urgently needed to feed a rapidly expanding world population.

The first published record of soybean trials in the U. S. was in 1804, and beginning in 1898 numerous introductions were made by the U.S. Department of Agriculture. The soybean industry of the United States is based on introductions from Manchuria, China, Korea, and Japan. At first soybeans were considered a hay crop, and even as late as 1940 the acreage grown for hay was equal to that for beans. Today, less than one-half million out of a total of 41.6 million acres are harvested for hay. The remainder of the crop is used as beans for production of oil, meal, and industrial products.

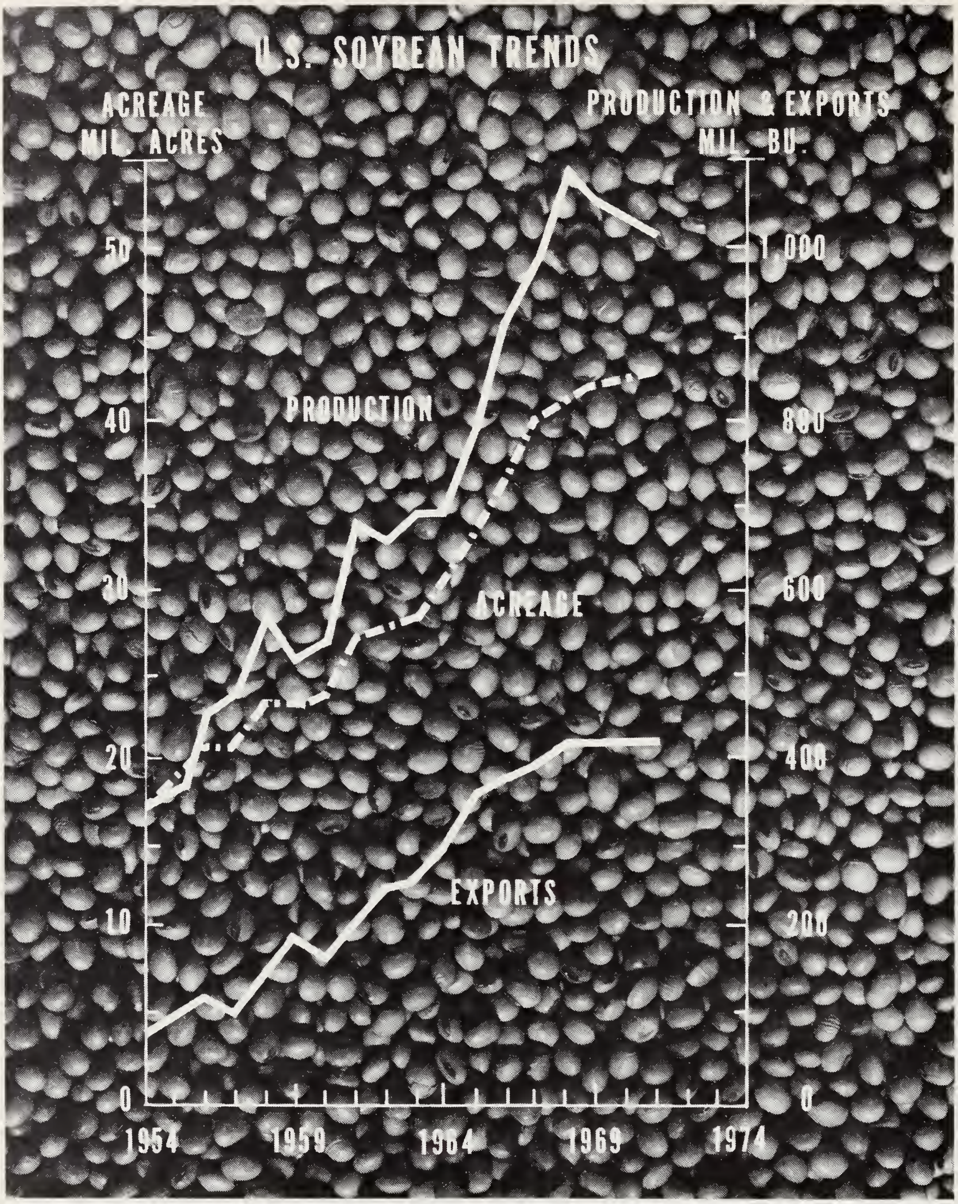
The U. S. area of production increased dramatically beginning about 1954. Yield per acre has been maintained or even increased, so total production per acre has more than kept pace with the startling increase in acreage. In volume of production in the U. S., soybeans are about equivalent to wheat (both are far below corn). Of the present world production, about 75 per cent is in the United States and 20 per cent in mainland China. U.S. exports of soybeans have increased from 140 million bushels in 1959 to 410 million bushels in 1971. About one-half of U.S. exports go to western Europe and one-quarter to Japan.

The early development of soybeans as a crop in the U.S. was centered in the Midwest, and most U.S. acreage is still in that area. However, southeastern states have increased their acreage greatly in recent years, primarily because of the development of better-adapted varieties, but partly because of the need for another crop and partly because of greater knowledge about the culture of soybeans in the South. For numerous reasons, soybeans have not become a volume commercial crop in the southwestern U.S.

It is estimated that 600,000 tons of soybeans or soybean products are used in California annually. Despite this large use (equal to 400,000 acres with a yield of 3,000 pounds per acre), California's agriculture has had a disappointing role in the production of the crop.

Soybean yield tests were started in California by the University of California as early as 1918, and in 1951 the U. S. Department of Agriculture and the University started research on soybeans at the Southwestern Irrigation Field Station in Brawley. This research, conducted principally in the Imperial Valley, was discontinued in 1963. The University also conducted extensive experiments throughout the San Joaquin and Sacramento Valleys in 1955, 1956, and 1957, and another soybean research program was started in 1966. The later was conducted cooperatively by the U. S. Department of Agriculture, Agricultural Research Service, Oilseed and Industrial Crops Research Branch, and the Departments of Agronomy and Range Science, Water Science and Engineering, Entomology, Agricultural Field Stations, and the Agricultural Extension Service of the University of California, Davis. A

[1] Submitted for publication May 25, 1972.



Soybean production, acreage, and exports, 1954–1971.

grant to the University of California by the Oil Seed Crops Research Trust helped finance the 1966 to 1969 project.

Almost 30 years of experience with soybeans in California were summarized in 1944 by B. A. Madson (1944), who reported that yields under commercial production, though occasionally quite good, were not high enough to attract farmer interest on a sustained basis. Where yields were good, as on bottom lands of the lower Sacramento River and warmer coastal valleys, other crops would yield a greater net cash return per acre. He noted that the soybean varieties then available were susceptible to spider mites and to shattering.

The problems of today are largely the same as those enumerated by Professor Madson in 1944. Double cropping, germ plasm that is somewhat tolerant to spider mites, and varieties less susceptible to shattering are new developments in the last 10 to 15 years that allow some hope for future production of soybeans in California, but additional research is needed to develop adapted varieties.

MORPHOLOGY AND DEVELOPMENT OF THE SOYBEAN PLANT

P. F. Knowles

The soybean *(Glycine max* [L] Merrill) a summer annual, was domesticated in north or central China from a closely related vine-like wild species *G. ussuriensis* Regel and Maack. It requires 75 to 175 days to mature, depending on the variety and the environment. Culture and harvest of the crop will be helped by an understanding of the development of the plant and seed.

ROOTS. Soybeans develop a tap root penetrating to depths of 5 to 7 feet with most of the branch roots in the surface 2 feet of soil. Root development ceases at about the time seed development begins.

Like other legumes, soybean roots develop nodules if the appropriate race or strain of *Rhizobium* bacteria is present. These nitrifying bacteria invade the plant through root hairs and form colonies, which appear as nodules. Each nodule contains millions of bacteria. The bacteria obtain carbodydrates from the plant, in return supplying the plant with nitrates which they produce from the nitrogen of the air. (This cooperative arrangement is called 'symbiosis.') The strain of bacteria required by soybeans, being absent from California soil, must be added to the seed just before planting (page 25).

STEMS. Stems are 1 to 6 feet tall, depending on variety and planting date. They are usually erect, though some long-stemmed varieties lodge readily. With close spacing, branches are seldom produced. Usually branches rise at the base of the stem and do not rebranch. In soybean varieties from northern latitudes the terminal growing point elongates until the plant matures, and does not terminate with a cluster of flowers or pods. These are called indeterminate types; such types continue vegetative development and stem elongation after flowering commences. The determinate types (usually with a southern distribution) have stems terminating in a cluster of flowers or pods. Determinate types have more branches and are usually shorter (the

Soybean plants terminating in a cluster of flowers or pods are called "determinate" types.

Soybean showing indeterminate growth.

stems cease elongation after flowering commences).

LEAVES. The cotyledons (two halves of the seed), following emergence from the soil, nourish the seedling for about 2 weeks from the beginning of germination. The first true leaves appearing above the cotyledons have single leaflets; thereafter, all leaves have three leaflets.

At or before seed maturity the leaves drop off, their loss being hastened by fall frosts. Under California conditions, in the absence of fall frosts, leaves may remain longer than they do in the Great Plains, and may be a problem at harvest.

FLOWERS. The flowers, small and inconspicuous, are found mostly in axils of leaves. They are borne on racemes (clusters) of 3 to 15 flowers. Structurally they are similar to flowers of other legumes, such as peas or alfalfa. They are white, some shade of purple, or combinations of white and purple. The flowers, opening early in the morning, are self-pollinated.

Soybean flowers are borne on clusters on the axils of leaves.

Flowers appear first at lower nodes, usually 6 to 8 weeks after planting, and develop progressively upward as the stem elongates. About 75 per cent of the flowers abort without producing pods. Shedding is increased by low fertility levels, drought, and red spider injury.

PODS. The pod generally has two to four seeds. The main colors are light straw-color, gray, or black, all of which may be modified in appearance by the color of the hairs on the surface.

Typical soybean specimens from five varieties grown in test plots. Pods have 2 to 4 seeds. Varieties are (left to right): Clarke, Lincoln, Hawkeye, Blackhawk, Brown Derby.

Table 1

COMPOSITION OF COMPONENT PARTS OF THE SOYBEAN SEED*

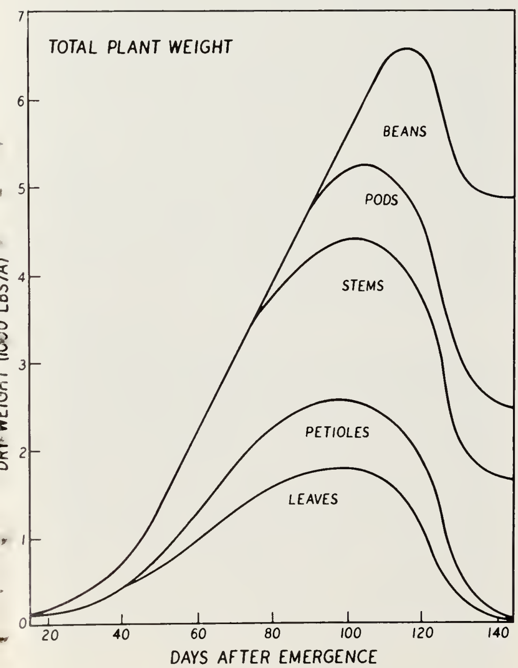
Part of seed	Proportion of seed	Dry matter	Nitrogenous substances	Carbo-hydrates	Fat	Ash
	per cent					
Entire seed	100	90.18	38.06	12.06	17.80	4.44
Cotyledons	90	89.43	41.33	14.60	20.75	4.38
Plumule	2	87.99	36.93	17.32	10.45	4.08
Seed coat	8	87.47	7.00	21.02	0.60	3.83

*From: The Soybean, by C. V. Piper and W. J. Morse. New York, N.Y.: McGraw-Hill Book Co., Inc., 1923. Used with permission of McGraw-Hill Book Company.

Varieties differ greatly in tendency to shatter, a tendency increased by the dry atmospheres prevailing in California. As a consequence, many varieties with acceptable resistance to shattering in the Corn Belt suffer severe seed loss before harvest in California.

PUBESCENCE. Most soybean varieties have a dense coat of hairs (pubescence) on the leaves, stems, and pods. Pubescence varies in degree and may be gray or brown in color. Smooth (glabrous) types have hairs only on the veins of the leaf.

SEEDS. Seed development requires about 35 days after pollination. Dry-matter accumulation varies from 60 to 90 pounds per day per acre. Commercial varieties grown for oil and protein have seed almost spherical in shape, ranging in size from 10 to 20 grams per 100 seed. Certain vegetable varieties, however, weigh up to 40 grams per 100 seed and are often flattened in shape. Some hay types may have flattened seed weighing less than 10 grams per 100 seed. The seeds of most commercial varieties are some shade of yellow, in some cases having a dark hilum (point of seed attachment). Seeds may also be green, black, brown, buff or combinations of these colors.



Development of soybean plant. (Adapted from Hanway and Thompson.)

Inside the seed coat are the two hemispherical cotyledons and between the cotyledons is the plumule (embryonic plant). Soybean seeds are easily injured by rough handling during harvest or in storage. Sometimes the injury is invisible (the cotyledons or plumule broken while the seed coat remains intact).

Table 1 gives the chemical composition of soybean seeds. Most of the seed is made up of protein (nitrogenous substances) and oil, with twice as much protein as oil (Morse, 1950, and Piper and Morse, 1923).

Seedling development. Soybean seeds germinate quickly, with the embryonic root (radicle) emerging first through the micropyle. The hypocotyl above the root and below the cotyledons grows rapidly. It is crooked in the middle, with the crook emerging through the ground first and pulling the cotyledons through behind it. Emergence occurs within 4 to 7 days under field conditions. After the cotyledons emerge the hypocotyl no longer elongates, so the cotyledons remain close to the ground.

Plant development. The figure on page 9, which is based on data from Iowa, gives the pattern for development of a soybean plant. Note that development proceeds slowly in early stages but becomes very rapid about 50 days after emergence.

ECONOMIC FACTS: SUPPLY, COMPETITION, USE

M. D. Miller, B. H. Beard

Farmers, oilseed processors, and oilseeds product users are all keenly interested in soybeans' potential for production in California for a number of reasons discussed below.

Large quantities of soybeans and soybean products are imported and consumed in the state annually. For example, the California State Department of Agriculture in 1965 reported that the California feeding industry alone used 150,836 tons of soybean meal, a large proportion of the total usage of 993,312 tons of all types of protein supplement (Thomas and Braun, 1965). Because of its high nutritional quality, soybean meal is expected to continue to expand into this market. Total usage of soybeans for all purposes within the state is now estimated at 600,000 to 700,000 tons yearly. Freight costs of these and of commodities based on soybean oil and meal are estimated at in excess of $22 million.

Alternatives or "new crops" such as soybeans are not only desirable but urgently needed because of governmental crop acreage restrictions on cotton, rice, and the feed grains, and because of new land currently coming under irrigation on the west side of the San Joaquin Valley. Although soybeans are a federally price-supported crop, to date there has been no economic need for soybean acreage-control programs. Existing California oilseed-processing facilities, particularly in the San Joaquin Valley, have a capacity which could be used in slack or off-season periods to process soybeans.

In recent years U. S. soybeans have been exported to Japan and other countries in great volume. For example, in 1970, 432.8 million bushels of soybeans were exported out of a total U. S. supply of 1,365.9 million bushels (USDA Economic Research Service 1971*a*). Soybean production in areas adjacent to such West Coast ports as San Francisco or Los Angeles should normally have a transport cost advantage over soybeans produced east of the Rocky Mountains.

Assuming an average yield of 3,000 pounds of soybeans per acre, 400,000 to 500,000 acres could potentially be devoted to the crop just to meet California needs, if local production costs can be competitive with the cost of imported domestic beans. Farm machinery generally available to California growers would be sufficient as specialized equipment is not needed for soybean production.

Cost of producing soybeans in California

Because soybeans have rarely been grown as a commercial crop in California, estimates of production costs are limited. Barnes and Burlingame (1967) reported 1966 Kern County cash materials and labor costs to be $82.75 per acre for a yield of 2,550 pounds of soybeans ($3.31 per cwt) grown on a single-crop-per-season basis. Their report lists additional costs which prospective growers in other areas must consider (page 14).

Amick and Allison (1968) reported the costs of growing soybeans in Georgia with an average yield of 1,734 pounds per acre as a full-season crop, and a yield of 1,530 pounds per acre following cereals in a two-crop rotation in a single year. These studies illustrate present cost-of-production advantages which other areas have in comparison with California. Total cash and interest on operating capital costs of producing soybeans were $37.62 per acre ($2.17 per cwt) on a single-crop basis and $31.77 ($2.07 per cwt) as a second crop in the season.

No land use or equipment depreciation charges were reported in the Georgia

studies. Comparison with the California study requires that appropriate additional charges be added. Assuming charges only one-third of those in California (total California depreciation and interest = $82.17 per acre), this would increase the Georgia costs by about $27.00 per acre, or to $3.72 per cwt and $2.95 per cwt, respectively. Compare these costs with the "All Costs at Varying Yields" column on page 14. The data clearly illustrate that California growers who are considering soybeans as an alternative crop must face the fact that soybeans are already grown on over 42.8 million acres in states where irrigation is not required and land values and other production costs are currently appreciably below those in California. To be competitive, we must produce 3,000 to 4,000 pounds of beans per acre with present costs or find ways of growing soybeans at lower costs per acre. If soybeans are grown in California immediately following a winter cereal or vegetable crop, then the first crop could be assigned an appropriate proportion of the annual overhead costs, including taxes, thereby reducing the total cost of growing soybeans by from 15 to 25 per cent.

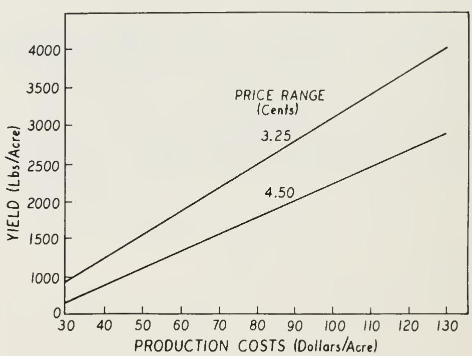
Economics of double cropping

In California, yields from experimental plots are similar for all seeding dates between April 1 and July 1 (pages 21–23). Consequently, there has been considerable interest in the possibility of including soybeans in a double cropping system. Lack of moisture at seeding time is not a problem in most of California because of irrigation.

Economic relationships. Success or failure of double cropping with soybeans depends on timing of each operation and the relationship of price of the beans, yield, and cost of production. Production costs determined for an individual farm can be more accurate than average costs. In areas where the land will be fallow during the summer unless used for soybeans, total costs for the year should be compared with the total returns as well as the costs and returns for alternate land uses. There are two aspects of increasing the profit from a crop. Generally the price received, although variable, is beyond the control of individuals. Thus higher yields per acre and lower cost of production are the principal components subject to changes by the producer. Yields for many areas of California have been determined from experimental plots and are reported here. Although individual producers and farms will have varying yields, usually the best yields will be close to those determined experimentally for the area.

The cost of production of soybeans can be varied by the individual producer. The methods of soil preparation before seeding can be varied as can be the number of cultivations and irrigations. (See "Management practices for various areas of California" page 18.)

The lowest price for soybeans during the last 10 years was 3¼ cents per pound and the highest was 4½ cents per pound (USDA Agricultural Statistics 1970). These two extremes in price were used to construct the following graph, which shows the relationships between price, yields and production costs. This graph can be used in two ways. First, if average yields for an area are known they can be compared with the production costs for an individual producer to determine if soybeans are a profitable crop under his conditions. Second, if production costs are known the lowest profitable yield can be determined. Intersection points of any comparison falling below the lower straight line will be a loss, above the upper straight line will be profitable, and between the two lines may be profitable, be a loss, or break even depending on the price at the time.



Soybean yields, production costs, and price relationships.

The long-term soybean outlook

Information in this section is based upon recent published reports of the Economic Research Service, USDA, Washington, D.C. (1966, 1971*a*, 1971*b*) and Foreign Agriculture Service, USDA, Washington, D.C. (1969, 1971*a*, 1971*b*). As of October 1971, the primary production of world food supplies of several types including vegetable oil, had increased to the point where many nations which had been historically considered as importers were on an export basis. In appraising the long-term outlook for soybeans, one must consider the total worldwide oil-supply situation. Depending on supply and price, many vegetable oils can be used interchangeably. Thus, one in excess supply tends to soften the price of competing substitute oils. World production of fats and oils in 1971 is projected to reach an estimated record 41 million metric tons (fat or oil equivalent), about 10 per cent above the 1963–67 average (USDA Foreign Agriculture Service 1971*b*). This estimate includes edible and industrial vegetable oils produced largely from oilseed crops, palm, animal, and marine oils and fats.

Unlike food grains, however, per capita increase in world production of edible fats and oils has not been striking. Worldwide, edible fats and oils output increased about 35 per cent from 1957 to 1968 while populations advanced 25 per cent (world production per person rose from under 18 pounds to 19½ pounds). The big increase in edible vegetable-oil production occurred in the developed countries, which accounts for about 60 per cent of total world production of edible fats and oils. World per capita consumption of food fats and oil is generally low compared with that in the U. S., where each person consumes about 50 pounds annually. There is opportunity for future export expansion of vegetable oil to the developing countries if the problem of low consumer buying power can be solved (USDA Economic Research Service 1971*b*).

U. S. position. All through the 1960's the U. S. has produced about one-fourth of world supply of oilseeds, fats, and oils, and provided one-third of world exports. This large vegetable-oil export program has been anchored to the rapidly expanding U. S. soybean production, where three-fourths of the world total was grown in 1969 (USDA Foreign Agriculture Service, 1969). Because about 25 to 32 per cent of the annual U. S. soybean crop is exported, short-term changes in world supply can exert considerable effects on the U. S. competitive position and unsupported farm prices for soybeans in any one year.

The data on page 14 show soybean production and use in the U. S. since 1959 (USDA Economic Research Service 1971*a*). The principal soybean-producing states include those in the corn and cotton belts, with the principal area of soybean production being the North Central states, the Mississippi delta, and the Middle Atlantic coast.

Soybean utilization

The soybean, long known as "the meat of the fields" in the Orient, has come to be known as "The Marvel Crop" in U. S. agriculture. Although about a century has passed since the crop was first introduced into the U. S. it was the modern chemurgic era that skyrocketed the crop into prime commercial importance. The crop's versatility accounts for the many uses to which it is put.

For forage. Soybeans are used for the production of hay. For hay of best quality, plants are cut when the seeds in the pods are about half developed. They are also grown in combination with other crops for pasturage and silage.

For human food. Production of soybean oil now far exceeds in volume and value that of any other edible vegetable oil. The oil is used in making margarine, shortening, salad oil, and other food products. Recent advances in food technology have created a high-volume market for processed soybean meal for human food, although it is still only a small percentage of the total usage. Soybean meal is used to make high-protein soy flour, which is used in diverse forms in breakfast cereals, breads, cakes, cookies, crackers, and fillings. Soy flour and grits (coarser particles) are used in pancake mixes, cake mixes, macaroni, dry foods, and packaged and canned food. Soybean meal products re-

SOYBEANS: ACREAGE, YIELD, AND PRODUCTION IN VARIOUS COUNTRIES, AVERAGE 1962–1966, ANNUAL 1968–1970*

Continent and Country	Acreage† Average 1962–66	Acreage† 1969	Yield Per acre Average 1962–66	Yield Per acre 1969	Production Average 1962–66	Production 1969
	1,000 acres	1,000 acres	Bushels	Bushels	1,000 bushels	1,000 bushels
North America:						
Canada	245	322	29.1	23.8	7,126	7,664
United States‡	31,602	40,857	24.3	27.3	768,672	1,116,876
Mexico	56	395	30.8	25.3	1,721	9,994
South America:						
Argentina	36	70	16.1	16.7	582	1,168
Brazil	957	2,297	16.1	15.2	15,367	34,906
Colombia	61	138	23.2	26.8	1,429	3,711
Paraguay§	18	69	20.7	15.9	370	1,102
Europe:						
Romania	22	133	10.2	14.1	228	1,870
Yugoslavia	16	11	20.2	18.8	330	201
U.S.S.R.	2,106	2,125	7.6	9.3	16,049	19,105
Africa:						
Nigeria‖	—	—	—	—	673	300
Rhodesia§ ¶	2	—	6.5	—	11	10
Tanzania**	10	—	12.1	—	125	—
South Africa§ ¶	22	33	5.2	7.9	113	257
Asia:						
Iran††	1	—	8.9	—	10	121
Turkey	14	20	12.5	16.7	178	331
China:						
Mainland	19,915	19,770	13.0	11.5	259,600	230,000
Taiwan	130	112	16.4	22.0	2,148	2,466
Cambodia	29	25	10.8	13.4	312	331
Indonesia	1,433	1,221	10.1	12.5	14,442	15,297
Japan	528	254	18.4	19.7	9,718	4,986
Korea, South	709	761	8.4	11.1	5,959	8,416
Philippines	5	4	12.7	12.3	59	44
Thailand§	77	51	14.4	21.4	1,112	1,102
Other countries	1,099	1,105	8.1	9.5	8,949	10,480
Total excluding Romania, U.S.S.R., Bulgaria, Hungary, Mainland China, North Korea, and North Vietnam§§	36,164	46,897	22.9	25.8	829,120	1,210,088
Estimated world total§§	59,229	69,944	18.8	21.0	1,113,273	1,470,868

* Years shown refer to years of harvest. Southern Hemisphere crops harvested in the early part of the year are combined with Northern Hemisphere crops harvested in the latter part of the same year.

† Harvested area as far as possible.

‡ Acreage harvested for beans.

§ Planted area.

‖ Quantities purchased by the Nigerian Marketing Boards for export.

¶ European farms only.

** Sales.

†† Less than 5 years.

§§ Includes estimates for the above countries for which data are not available and for minor producing countries.

Data from USDA, Foreign Agricultural Research Service reports.

SAMPLE COSTS OF PRODUCING SOYBEANS IN KERN COUNTY, 1966*

Operation	Hours per acre	Labor	Fuel and repairs—equipment	Material and other costs		Total sample costs
		Cash and Labor Cost Per Acre				
Cultural:						
Land preparation	2.5	$3.50	$2.75			$ 6.25
Plant . .	.5	.70	.55	Seed: 70 lbs. @ 12¢	$ 8.40	9.65
Irrigate: 1 pre-6 crop	8.0	9.60	2.50	Water: 3 ft. @ 6.00	18.00	30.10
Cultivate: 3 times	1.5	2.10	1.65			3.75
Taxes					12.50	12.50
Miscellaneous overhead		2.60	2.75		4.65	10.00
Total cultural costs		$18.50	$10.20		$43.55	$72.25
Harvest:						
Combine					$ 8.00	
Haul					2.50	
Total harvest costs						$10.50
Total cash and labor costs						$82.75

All Costs at Varying Yields: Pounds per acre	Cost per cwt.
1,500	$10.99
2,000	5.25
2,500	6.60
3,000	5.50
3,500	4.71
4,000	4.12
4,500	3.66

Investment	Per acre	Annual Cost: Depreciation	Annual Cost: Interest	
Land	$900.00		$54.00	
Irrigation facilities	200.00	$15.00	6.00	
Tractor 5½ hrs.		3.30	1.27	
Equipment	20.00	2.00	.60	
Total		$20.30	$61.87	$82.17
Total cost per acre				$164.92

* Data prepared by Roy M. Barnes and Burt B. Burlingame

SOYBEANS: SUPPLY DISPOSITION, ACREAGE AND PRICE IN THE U.S., 1959–72

Item	1959	1965	1970	1972*
	Year Beginning September			
	Supply and Disposition (million bushels)			
Supply				
Beginning Stocks, Sept. 1	87.8	29.7	230.1	71.9
Production	532.9	845.6	1,123.7	1,351
Total supply	620.7	875.3	1,353.8	1,423
Disposition				
Crushings	394.0	537.5	760.1	765
Exports	139.9	250.6	433.8	510
Seed	29.3	42.9	48.3	)
Feed	1.5	.9	1.0	)73
Residual	4.2	7.8	11.7	)
Total disposition	568.9	839.7	1,254.9	1,348
Ending stocks, Aug. 31	51.8	35.5	98.9	75.0

Item	1959	1965	1970	1972*
	Year Beginning September			
	Acreage and yield (million acres)			
Acreage planted	23.3	35.2	43.3	46.4
Acreage harvested for beans	22.6	34.4	42.0	45.8
Per cent harvested	97.0	97.7	97.0	98.7
	(bushels)			
Yield per acre harvested	23.5	24.5	26.8	29.5
	Price (dollars)			
Price per bushel				
Support (U.S. farm basis)	1.85	2.25	2.25	2.25
Received by farmers	1.96	2.54	2.84	3.20†
No. 1 yellow, Ill. pts.	2.07	2.91	3.00	—
No. 1 yellow, Chicago	2.17	2.98	3.05	—

* September indications.
† Forecast.
Data from USDA Economic Research Service reports.

cently developed are used as a wholesome, nutritious binder for making sausage and meat loaves and for whipping agents. They are also being used to produce high-quality meat-like and milk-like products.

Protein for livestock feeding. Soybean meal is the first ranking vegetable protein livestock feed supplement in the U. S. and 90 per cent of the meal produced is utilized in this manner. Every pound of soy oil produced leaves 4 pounds of high-protein meal. It has proved an excellent protein feed for livestock and poultry.

Industrial uses. New chemical knowledge has proven soybeans to be an excellent source of structural and decorative materials for homes, offices, and factories.

Soybean meal is used in making a series of protein products which, in turn, are made into low-cost adhesives. These powerful adhesives are used for many purposes, including plywood. Other uses include wallpaper, coated printing papers, and adhesive tape. They are used in the manufacture of the new cold-water paints.

Soybean oil is used to make paints, varnishes, enamels, and lacquers. Linoleum, putty, caulking compounds, leather dressings, lubricating greases, and waterproofing coatings are all now being processed from soybean-oil formulations.

CLIMATE FACTORS

P. F. Knowles

The soybean is a warm-season crop which requires the same general climate as corn, and this probably explains why it has been so successful in the Corn Belt. Day length and humidity are very important factors in soybean production.

Day length. All varieties will flower 20 to 28 days after emergence if there are 12 hours of daylight or less; in other words, it is a short-day plant. When day lengths are over 12 hours, varieties differ in flowering response. Varieties with the shortest day requirements are found in semi-tropical and tropical areas; under long days these varieties grow vegetatively, either failing to flower or flowering only late in the growing season, as days shorten. Long-day varieties, which are adapted to northern latitudes in the northern hemisphere, flower very early under short-day conditions (page 41).

The flowering response of soybeans to different day lengths is determined by a pigment named "phytochrome" which is a soluble protein that is very unstable once it is extracted from the plant (it has a half-life of 20 minutes at room temperatures). Phytochrome exists in two photoreversible forms: P_r, with absorption in the red portion of the light spectrum (wavelengths of 590 to 680 mμ); and P_{fr}, with absorption in the far-red portion (wavelengths of 700 to 800 mμ). Irradiation of the plant with light of 590 to 680 mμ shifts the pigment to P_{fr}, the active form of phytochrome that stimulates flower development. P_{fr} reverts to P_r, the inactive form, quickly in sunlight (450 to 700 mμ) and slowly in darkness. The degree of reversal is less with long nights (short days); hence, flowering response is stimulated by short days.

Humidity. Soybeans require a moist warm climate, and have been economically unsuccessful in areas with prolonged periods of low relative humidity. Prolonged low humidity seems to aggravate two problems: shattering and spider mites. Many varieties developed for the humid areas of the Corn Belt tend to shatter excessively as they approach maturity in a dry climate, although recently developed varieties are partially resistant to shattering. Even with less shattering, spider mites are a serious problem under dry, dusty conditions. Mites are a problem in the soybean production areas of the U. S. only after abnormally long periods of drought, but they are generally prevalent throughout California.

Temperature. Soil temperatures at seeding depths should average 65° F before

planting; at lower temperatures emergence will be delayed and some seedlings will not survive.

Temperatures above 100° F slow soybean growth. When plants are flowering, hot dry winds seriously reduce seed setting. Seedlings and fully developed plants are not injured by light frosts.

SOIL FACTORS

G. H. Abel, A. J. MacKenzie

Soil types. Soil types favorable for the growth of other crops are suitable for soybeans. Ideal for optimum growth are deep, friable soils with good drainage and aeration characteristics; also desirable are medium-textured soils with a high water-intake and water-holding capacity. Avoid saline soils containing soluble salts above 5 to 7 millimhos per cm (mmhos per cm) electrical conductivity of saturation paste extract.

Effect of salinity. Salinity decreases availability of soil water to plants. The salts responsible for salinity are mainly cations of sodium, calcium, and magnesium, and anions of chloride and sulfate (table 2). These salts increase the osmotic pressure of the soil solution in direct proportion to the salt concentration. Salt concentration increases rapidly as soil moisture is depleted. Saline soils require irrigation more often than nonsaline soils because the range of available moisture is less.

Toxicity to the chloride ion is quite apparent in many of the varieties developed for highly leached soils east of the Rocky Mountains. Seed germination and seedling to maturity are two separate growth stages that may show high, intermediate, and low tolerance to excessive chloride in the soil. Chloride tolerance for the two stages of growth are unrelated, and all combinations have been found in different varieties of soybeans. For example, the Lee variety has low chloride tolerance during germination but high chloride tolerance during later growth, whereas the Jackson variety has the reverse. Other varieties may have either high or low chloride tolerance during both stages of growth. For further details see Abel and MacKenzie (1964).

During seed germination, rate and per cent emergence of all soybean varieties are decreased when the salt concentration of the soil saturation paste extract is above 7 mmhos per cm. Salt-susceptible varieties are more affected than the tolerant. At lower salinities all varieties reach ultimate emergence, although the tolerant do so in 1 week and the susceptible in 3 weeks.

During the growth stage, toxicity in the chloride-susceptible varieties appears as an incipient light-brown necrosis beginning at the leaf tips, advancing to the leaf margin, and then moving inward until the whole leaf is affected. The entire plant can become affected, with death ensuing. In direct contrast are the chloride-tolerant varieties, which do not show necrosis to salinities up to 10 mmhos per cm. Above this level, the plant tissues die from physiological drouth and root deterioration.

TABLE 2
CHEMICAL COMPOSITION OF SATURATION-PASTE EXTRACTS OF THREE SALINE SOILS IN THE IMPERIAL VALLEY

Soil	Electrical conductivity	Soluble cations				Soluble anions		
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	$SO_4^{=}$	Cl^{-}
	mmhos. per cm.	*meq. per liter*						
Imperial silty clay	6.8	30.5	19.6	38.0	1.7	6.5	58.3	26.1
Meloland loam	7.0	32.4	19.7	32.0	0.6	3.8	52.6	29.5
Holtville silty clay	5.0	24.2	12.0	30.0	1.0	7.5	48.4	17.0

Uptake of chloride in stems and leaves is high in chloride-susceptible varieties, but tolerant varieties are able to exclude virtually all the chlorides. As an example, 1-month-old plants of the susceptible variety Jackson and the tolerant variety Lee contained 30,000 ppm and 140 ppm chloride in the stems respectively, and 50,000 ppm and 100 ppm chloride in the leaves, respectively.

Seed yield of the chloride-susceptible varieties is reduced when soil salinities are 5 mmhos per cm or higher, whereas the chloride-tolerant varieties show no reduction in yield until salinities exceed 9 mmhos per cm. Chloride-tolerant soybeans should thrive well in salinities of 8 mmhos per cm if emergence is good and there are no other limitations on growth. A salinity of 8 mmhos per cm reduces height even with resistant varieties, and there is a harvest problem when a portion of the podding is too close to the soil surface for combine harvest. The usual recommendation is to select fields with salinities no higher than 5 or 6 mmhos per cm, because higher salinities indicate other serious problems which would limit soybean growth.

The leaves of susceptible varieties are a paler green when grown in a substrate with moderate to high concentrations of salt, but leaves of tolerant varieties remain normal green under similar conditions.

Effect of boron. Soybeans have a low requirement for boron, with 0.1 ppm available boron content of soils required for optimum growth (Berger, 1949). Boron toxicity effects have been observed in the Central Valley of California. Boron in excess of 0.5 ppm causes a speckled type of necrosis, which may lead to plant death. Excessive boron reduces plant metabolism and seed yield.

Nutrient uptake and fertilizer needs. Soybeans grown in the Imperial Valley have produced 4.3 tons of dry matter per acre (oven-dried at 70°C). This included 3.0 tons of vegetative material (stems, leaves, and petioles) and 1.3 tons of fruiting material (pods and beans). Iowa-grown soybeans have been reported to produce 3.2 tons of dry matter per acre, 2.1 and 1.1 tons of vegetative and fruiting portions, respectively (Hanway and Thompson, 1967).

Nitrogen content of soybeans, obtained through nitrogen fixation and uptake from the soil, is approximately 250 pounds per acre. The harvested seed contains 110 pounds of nitrogen, leaving 140 pounds per acre to be returned to the soil with plant residue.

Phosphorus and potassium uptake by soybeans has been reported to be respectively 17 and 77 pounds per acre. Harvested seed per acre contains 12 pounds of phosphorus and 40 pounds of potassium (Hanway and Thompson, 1967).

Soybean plants require other nutrients, such as calcium, magnesium, sulfur, iron, manganese, molybdenum, zinc, and copper. Unlike nitrogen, phosphorus, and potassium these nutrients are not commonly deficient in soils.

Although the very early stages of growth require only relatively small amounts of nutrients, early plant growth is promoted by high concentrations of nutrients in the root zone at that time. If needed, fertilizers can be applied preplant by broadcast spreading and discing before bed preparation, but preferable application is in a band 1 to 2 inches to the side and slightly below the seed. Placing the fertilizer too near the seed or with the seed can result in salt injury to the plant. In the Midwest, top soybean yields are generally obtained on fields with high potassium and potash levels built up by a continuous program of high fertilization.

Nitrogen. Nodulated soybeans generally do not respond to nitrogen fertilizer as do nonlegume crops. When properly nodulated, soybean roots may derive a considerable portion of the nitrogen needs of the plant from nodules through the fixation of atmospheric nitrogen. Applications of nitrogen tend to retard the nodulation of seed-inoculated soybeans planted in rhizobia-free soil. Applications of 100 pounds of nitrogen at planting time in the Imperial Valley, where rhizobia were not present in the soil, resulted in poorly nodulated soybeans and yields of only 360 to 960 pounds of beans per acre. Omitting nitrogen at planting time permitted good nodulation and yields of

2100 to 2400 pounds of beans per acre (Carter and Hartwig, 1963).

Initially the soybean seedling is exclusively dependent on the soil and cotyledons for nitrogen and must wait for the development of nodules for symbiotic nitrogen supplies (Ohlrogge, 1963). Seedling soybean leaves will show nitrogen-deficiency symptoms when grown in nitrogen-deficient soil, but with proper inoculation nitrogen fixation initiates normal growth 4 or 5 weeks after emergence. Studies in the Imperial Valley have shown no growth responses to different levels of nitrogen fertilizer applied to nitrogen-deficient soil at preplant and bloom stages.

Phosphorus. The roots absorb phosphorus and translocate it to the plant parts in different amounts. The leaves and plant top contain about twice as much as the stems. During plant maturation, about 75 per cent of the phosphrous moves into the seed.

In the South, phosphorus applied as a fertilizer will induce a response in soybeans when the soil contains less than 40 pounds per acre of this nutrient. No response to phosphorus has been obtained in the Imperial Valley, probably because the soil contained the minimal amounts needed for optimum plant growth. Therefore, when soil phosphorus is less than the minimal, apply approximately 50 pounds of P_2O_5 per acre for the soybean crop. Additional phosphate fertilizer would be reserves for succeeding crops.

Potassium. This highly mobile constituent in the plant is particularly abundant in young tissues. The soil is well supplied with potassium, and it should never be exhausted where irrigation water is applied from watersheds which provide dissolved potassium salts.

Magnesium and sulfur. If deficient, magnesium and sulfur should be incorporated in soil as fertilizer supplements. Magnesium is highly mobile in the plant and is used mainly in forming the chlorophyll molecule and in certain enzymatic reactions. Sulfur promotes root nodulation in addition to other plant functions. None of the other essential elements has been found deficient. If and when they do become deficient they should be added to the soil for optimum growth.

MANAGEMENT PRACTICES FOR VARIOUS AREAS IN CALIFORNIA

B. H. Beard, P. F. Knowles

If soybeans are to become a successful crop in California, they will not only have to be profitable but be more profitable than other crops that could be grown at the same time at comparable risks. Although soybeans can be grown as hay, silage, or green manure crops the primary market is for the beans. At present yield levels (2000 to 3000 pounds per acre) it appears that double-cropping offers the best possibility for soybeans to succeed as a profitable crop in California.

Soybeans will fit into most cropping systems used by California farmers growing grain crops. All cultural operations can be handled by row-crop equipment used for seeding and cultivating cotton or corn with only minor adjustments. A properly adjusted grain combine can be used for harvest. Because the soybean is a legume, it does not deplete the soil of nitrogen. In soybean areas the crop has been observed to have a beneficial effect on soil structure. It produces minimum residue quickly and easily incorporated into the soil during preparations for seeding the following crop.

In major soybean production areas of the U. S. it is generally a full-season crop, occupying the land from May through October. In the South, and in southern portions of the Corn Belt, a small percentage of the total soybeans are also grown as the second crop in a 2-crop 1-

year rotation along with small grains. Lack of moisture at seeding time has been the major hazard to that practice in those areas.

Although yields from experimental plots in California tend to be higher from earlier seeding dates, yields are not greatly reduced by planting as late as July 1; as a consequence there has been considerable interest in the possibility of including soybeans in a double-cropping system. Lack of moisture at seeding time need not be a problem in California if crop irrigations can be given when needed.

Imperial Valley. Soybeans have been grown here in experimental plots following early-harvested sugar beets and following barley. The minimum tillage needed following sugar beets caused no special problems. The beds were thrown up with furrowing shovels, and soybeans were sown on top of the ridges.

Following barley, the field should be disced and irrigated. After 2 or 3 weeks the soil is dry enough to make beds and plant the soybeans. An irrigation must follow within 2 days after sowing. Irrigations cause weed seeds and volunteer barley to germinate, but the weeds can be controlled with herbicides if it is necessary and the barley will die or be stunted by hot weather during July and August. This system requires attention to details and careful control of the timing of the various operations. If the barley can be harvested during the middle to later part of May, and the initial discing and pre-irrigation completed around June 1, there will be adequate time to seed the soybeans before July 1.

Southern San Joaquin Valley. In the southern San Joaquin Valley a 1-year cropping system of potatoes and soybeans appears practical. Following potato harvest, the soil is generally loose and requires reshaping of beds before soybeans are sown. Experimental soybean plots following potatoes on land of the Kern County Land Company near Wasco have shown that careful water management is required to obtain good stands. Growing soybeans as green manure between potato crops seems to help control potato scab due to *Streptomyces scabies.* It is not known if harvesting a crop of soybeans between potato crops would have the same effect. Soybeans and barley have not been tested but appear possible in a double-cropping system in the area.

Central San Joaquin Valley. Extensive double-cropping experiments have been carried out at the West Side Field Station, using barley and soybeans. Barley is broadcast on a level seed bed, and beds are thrown up with furrowing shovels. A single heavy irrigation will usually germinate the barley seed and produce good stands. After the barley harvest the soybeans are seeded into the top of the beds and immediately irrigated to germinate the seed. Care must be taken to thoroughly wet the bed to the location of the seeds.

Double-cropping minimum-tillage experiments were conducted in 1968 and 1969 in conjunction with herbicide tests described in another section of this report (only the tillage effects are discussed here). Three levels of pre-sowing tillage were used: no tillage; a sectioned rolling cultivator, and a power-driven rotary cultivator. These respectively represented none, medium, and thorough tillage. The barley straw was burned on half of each

TABLE 3
YIELD DATA FROM DOUBLE-CROPPING EXPERIMENTS WITH SOYBEANS AT THE WEST SIDE FIELD STATION, FIVE POINTS, 1968 AND 1969

Preplant tillage	Burned			Nonburned			Two-year average
	1968	1969	Average	1968	1969	Average	
	lb. per acre						
None	1505	1380	1443	1375	1388	1382	1412
Medium	1490	1338	1414	1577	1284	1431	1422
Thorough	1460	1396	1428	1600	1416	1508	1468
Average	1485	1372	1429	1517	1362	1440	1434

Table 4
YIELD DATA FROM TESTS OF SOYBEAN VARIETIES AND SELECTIONS GROWN ON SUMMER FALLOW AND AFTER BARLEY CUT FOR HAY, DAVIS, 1957

Maturity group	Number of entries	Summer fallow	After barley
		lb. per acre	
0	6	2137	2225
I	8	1773	1995
II	15	1764	1580
Average	–	1891	1933

replication, and was shredded with a flail-type cotton-stalk chopper on the other half. A starter application of nitrogen fertilizer (25 pound N per acre) was chiseled about 5 inches deep into the beds. Inoculated seed was sown into the dry beds in June and the test area was irrigated immediately. A 5-foot by 43.5-foot (0.005 of an acre) strip was combined from each plot. Table 3 shows yields for each experiment. The varieties Wayne and Kent were used, respectively during 1968 and 1969. Tillage differences were not associated with significant yield differences, and yields did not differ significantly whether the straw was burned or shredded. Burning the straw is wasteful of organic matter and contributes to atmospheric pollution. From a cost standpoint, the no-tillage plots were obviously more economical. The biggest problem is keeping the inoculum alive in the hot, dry soil until the post-seeding irrigation water reaches the seed.

With the proper varieties of soybeans, harvest can be in October or the first part of November. Thus the following rotational crop can be sown in November or December.

Seed size and quality, as well as oil content and meal percentage, were not affected by the tillage or straw treatments. In a similar experiment, yield was not affected by increased amounts over 25 pounds of nitrogen per acre.

Southern Sacramento Valley. In 1957, variety tests were sown on both summer-fallow land and on stubble land after a crop of barley cut for forage in early June. After the barley stubble was disced down the entire test area was furrowed and irrigated prior to planting. A level seedbed was then prepared by discing and harrowing. Plantings were made in rows 30 inches apart on June 20. Plots were single rows, 20 feet long, with 16 feet of row cut for yield determinations. All seed was inoculated. Yields for any maturity group were essentially the same whether sown on summer fallow or sown after barley (table 4).

SOWING METHODS AND PRACTICES

P. F. Knowles, G. H. Abel, B. H. Beard

Sowing is a critical operation in growing soybeans because often crop failures can be traced back to errors in choice of seed, rate of depth of seeding, choice of wrong type of inoculum, and so on. Choice of variety is so important to economic success that it is discussed in a separate section (pages 41–43) .

Seedbed preparation. Seedbed preparation varies from one area to another of California, but will be about the same as that used for other irrigation row crops in the district. (See pages 18–20 for seedbed preparation details for soybeans as the second crop.)

Good stands have frequently been obtained with flat plantings, provided the seedbed is level and moisture is maintained close to the surface of the soil. Flat plantings are used in the Midwest and in

the South. One disadvantage of flat plantings in California becomes apparent at harvest. When furrows are prepared for irrigations, soil is thrown to the base of the plants, in effect producing a raised bed. Raising the bed after plant establishment will decrease the distance between the soil surface and the lowest pods, thereby increasing bean losses during harvest.

Success is best achieved with sowings made on top of raised beds. To facilitate combine harvesting, beds should be thoroughly settled, uniform in height and shape, not too high, and free from clods. They should be firm, with moisture near the surface of the soil.

Quality of seed. It is important to use high-quality unbroken seed having at least 85 per cent germination. Use a germination test to determine the number of seed that will germinate and produce strong seedlings. The viability of undamaged seed is short-lived; 1 year of non-airconditioned shed storage reduces the germination level considerably. Where possible, certified seed grown the previous season should be used. Until soybeans are regularly grown in California, arrangements for seed purchase will be necessary well in advance of the seeding date.

Date of seeding. Optimum seeding dates are not greatly different for most areas of California. For economic reasons it is generally advisable to plant soybeans as the second crop in a double-cropping system after a cereal or vegetable crop. Other advantages of later dates of seeding are: (1) the growing season is shorter, with less water required and less weed control; (2) flowering occurs when days are shorter, after the high temperatures of mid-summer; and (3) pods mature in the fall, when relative humidities are higher and shattering is less.

In the Imperial Valley the highest yields for Lee (Maturity Group VI), an adapted variety, were obtained from plantings made between mid-May and mid-June (table 5 — maturity group classifications are explained on page 41). With this range of planting dates, maturity varied over a period of one week and height was about the same. Plantings after July 1 were distinctly and progressively shorter in height and lower in yield. If an adapted short-day variety, such as Lee, is planted in February and March in the Imperial Valley, the plant will begin to flower very soon after stem elongation begins because the days are short. Because of the longer days in May and June the plant enters a vegetative phase and stops flowering. It will begin flowering again later in the season, but the total yield will be low, and the seed quality poor. Lodging may result from the excessive vegetative growth caused by the long growth period (Abel, 1961).

Yields of the variety Clark (Group IV), sown in a test at the U.S. Cotton Research Station at Shafter, were above 3000 pounds per acre when sown on June 11 and June 25 (table 6). In a seeding on July 16 the yield had dropped about one-third. The seeding of June 25 gave less lodging and shorter plants than that of June 11. Oil content decreased with later dates of seeding.

Table 5

AVERAGE PERFORMANCE OF SOYBEAN VARIETY LEE (MATURITY GROUP VI) AT THE USDA SOUTHWESTERN IRRIGATION FIELD STATION, BRAWLEY, 1957

Date of planting	Planting to flowering	Flowering to maturity	Date ripe	Plant height	Seed quality score*	Yield
	days			*in.*		*lb. per acre*
May 2	81	101	10/31	30	2.7	1842
May 15	75	92	10/29	31	2.3	2598
May 29	69	85	10/30	35	2.7	2394
June 18	59	82	11/6	31	1.8	2532
July 3	55	74	11/9	18	1.3	1506
July 15	46	72	11/10	16	1.0	1824
Aug. 2	40	75	11/25	7	1.0	648

*1 = excellent, 5 = poor.

TABLE 6

AVERAGE PERFORMANCE OF SOYBEAN VARIETY CLARK (GROUP IV) AT THE U.S. COTTON RESEARCH STATION, SHAFTER, 1957

Date sown	Date mature	Height	Yield	Oil*	Protein*
		in.	*lb. per acre*	*per cent*	
June 11	Oct. 25	52	3065	20.0	37.1
June 25	Nov. 4	49	3175	18.6	35.8
July 16	Nov. 26	44	1930	17.8	36.7

*Basis 10% moisture.

At the West Side Field Station in 1966 and 1967 yields decreased progressively from mid-May to mid-June planting dates (tables 7 and 8). Boron injury was observed in these tests, and the low yields may have been a result of this injury. Mite damage has usually been severe and in 1967 the difference between the yields of the May 15 and June 6 planting may have been due to greater insect injury with the latter date of planting.

At Davis in 1955, Group O varieties did not differ appreciably in yield between plantings on May 16 and July 2 (table 9). But with Groups I and II there was a greater difference in favor of the earlier planting. In 1955, yields were mostly above 2,000 pounds per acre. In 1956, however, where maximum yields were rarely above 2,000 pounds per acre, the May 15 and June 27 plantings were similar in yield, considering the varieties of Groups O, I and II (table 10). In 1955, the May 16 planting required eight irrigations after planting, and the later planting three.

In 1955, oil content was 3.0 to 3.5 per cent higher with the earlier seeding date, and protein content lower by the same amount. Within each seeding date, earlier-maturity groups had slightly higher levels of both oil and protein. In 1956, the earlier planting date had slightly higher oil content and slightly lower protein content.

Row spacing. A vast amount of experience in the U. S. soybean-growing areas indicates that rows 20 to 24 inches apart will yield 10 to 15 per cent more than will wider spacings. In the South, however, where branching is more extensive, yields in wider row spacings have not been reduced even up to spacings of 40 inches (Hartwig, 1954).

Because irrigation is required in California farmers growing soybeans use single rows usually spaced 28 to 30 inches apart. Where double-row beds are used, row spacings are 12 to 16 inches on the bed and 24 to 28 inches over the furrow, with a total of 40 inches between centers of beds. Because of salt accumulation at the top of beds in the Imperial Valley, rows

TABLE 7

YIELD AND OIL CONTENT OF SOYBEANS SOWN AT DIFFERENT DATES AT THE WEST SIDE FIELD STATION, FIVE POINTS, 1966

Maturity group	Number of varieties*	Yield			Oil content†		
		Seeding dates			Seeding dates		
		May 25	June 8	June 22	May 25	June 8	June 22
		lb. per acre			*per cent*		
I	2	962	788	758	21.8	21.6	21.8
II	4	1067	894	832	21.3	21.8	22.0
III	3	1160	904	774	20.6	22.2	22.9
IV	3	1292	951	728	20.0	22.5	23.7
V	1	988	574	487	19.2	19.9	19.3

*Group I = A-100 and Chippewa 64; Group II = Adams, Harosoy 63, Hawkeye and Lindarin; Group III = Adelphia, Shelby and Wayne; Group IV = Clark 63, Delmar and Kent; Group V = Hill.

†Basis 10% moisture.

TABLE 8
YIELD OF SOYBEANS SOWN AT DIFFERENT DATES
AT THE WEST SIDE FIELD STATION, FIVE POINTS, 1967

Maturity group	Number of varieties*	Seeding dates					Maturity group average
		Apr. 13	May 15	June 6†	June 22†	July 17	
I	2	1154	1530	1532	1106	1124	1289
II	2	1573	1890	1397	906	1326	1418
III	1	1341	1561	1306	991	1531	1346
IV	1	–	1128	1083	974	1169	1087
Seeding date average‡		1359	1680	1433	1003	1286	1353

*Varieties were: Group I = A-100 and Hark; Group II = Amsoy and Harasoy; Group III = Wayne; Group IV = Clark 63.

†Insect damage severe.

‡For groups I, II, and III only.

TABLE 9
YIELD AND OIL AND PROTEIN CONTENT OF SOYBEANS
SOWN AT TWO DATES, DAVIS, 1955

Maturity group	Number of varieties	Sown May 16			Sown July 2		
		Yield	Oil*	Protein*	Yield	Oil*	Protein*
		lb. per acre	*per cent*		*lb. per acre*	*per cent*	
0	16	2445	21.0	39.8	2339	18.0	42.0
I	5	2967	21.5	39.7	2184	17.8	42.2
II	16	2571	21.1	37.2	2083	17.4	41.2
III	10	2196	20.4	38.2	–	–	–
IV	14	1327	20.0	38.5	–	–	–

*Basis 10% moisture.

TABLE 10
YIELD AND OIL AND PROTEIN CONTENT OF SOYBEAN VARIETIES
SOWN AT TWO DATES, DAVIS, 1956

Maturity group	Number of varieties	Sown May 15			Sown June 27		
		Yield	Oil*	Protein*	Yield	Oil*	Protein*
		lb. per acre	*per cent*		*lb. per acre*	*per cent*	
0	17	1632	20.5	40.3	1601	19.6	41.1
I	9	1399	20.1	41.1	1532	19.6	41.7
II	19	2010	–	–	2028	–	–
III	16	1548	–	–	–	–	–
IV	16	1854	–	–	–	–	–

*Basis 10% moisture.

there are sometimes located on the shoulder or side of sloped beds.

Two experiments involving plant and row spacings were conducted in the Imperial Valley, one in 1954 and one in 1957. In both experiments, seed yield was little affected by increasing plant populations within rows ranging from 20 to 40 inches apart. The narrower between-row widths increased yields 6 per cent in the earlier experiment and decreased it 7 per cent in the later. The plants compensated for the different between-row spacings in several ways. Branching increased from 1.8 branches per plant in the 20-inch between-row spacing to 3.16 branches in the 40-inch rows. Seeds per pod were reduced from 2.5 at the wider row spacing to 1.2 at the closer ones. At plant spacings of 8.4 plants per foot, 3.7 plants failed to develop at the 20-inch between-row spacing and 1.9 plants at the 40-inch.

Table 11

PLANT HEIGHT, YIELD, AND OIL AND PROTEIN CONTENT OF SOYBEAN VARIETIES SOWN AT DIFFERENT RATES, DAVIS, 1955*

Variety	Seeds sown	Number plants	Plant height	Yield	Seed analyses	
					Oil†	Protein†
	per foot		in.	lb. per acre	per cent	
Chippewa	6	5.6	46	2332	19.5	36.4
Chippewa	12	10.1	51	2181	19.4	35.1
Chippewa	18	9.4	44	2259	19.4	36.0
Chippewa	24	12.5	46	2144	21.1	35.9
Hawkeye	6	5.8	57	2346	18.9	34.6
Hawkeye	12	10.5	50	2102	19.0	34.5
Hawkeye	18	11.4	48	2093	18.7	35.6
Hawkeye	24	14.0	51	2375	18.7	35.9

*Date sown: May 16; irrigations: 3; treated with a miticide July 6; and date mature: Chippewa September 10, and Hawkeye September 25.

†Basis 10% moisture.

Seed size was unaffected by between-row spacing. Per cent oil tended to increase and protein to decrease at the wider between-row spacings.

In one test at Davis in 1955, the varieties Chippewa and Hawkeye were sown at between-row spacings of 12, 18, 24, and 30 inches, with about 8 plants per linear foot of row. Early defoliation by mites caused low yields, more so in Hawkeye because it matured later. Hawkeye was equally good at all spacings (900 to 950 pounds per acre), apparently because it grew taller and filled in the area between rows at all spacings. Chippewa, being shorter and arrested early in development by mites, was unable to fill in the area between the rows. As a consequence, yields were reduced as spacings increased (1300 pounds per acre at 12-inch rows, and 840 pounds per acre at 30-inch row spacings).

Rate of seeding. Recommended rates of seeding in the U. S. soybean-growing areas are about 55 pounds per acre for 40-inch rows, 65 pounds per acre for 30-inch rows, and 75 pounds per acre for 20-inch rows. This works out to an average of about 10 seeds per foot of row, irrespective of between-row spacing. Experience in California supports this recommendation. However, in more productive environments in the Midwest where excess vegetative growth and early lodging may be a serious problem lower seeding rates (6 to 8 seeds per foot of row) may be more desirable (Cooper, 1971).

In a test at Davis in 1955, yields showed no significant differences where plant spacings ranged from about 6 to 14 plants per foot of row and rows were 30 inches

Table 12

NITROGEN UPTAKE, SEED YIELD, AND DRY-MATTER PRODUCTION OF UNINOCULATED AND INOCULATED SOYBEANS WITH AMMONIUM NITRATE APPLIED AT DIFFERENT RATES, USDA SOUTHWESTERN IRRIGATION FIELD STATION, BRAWLEY, 1955

Lee soybean seed	Nitrogen applied*	Leaf color†	Number of nodules‡	Nitrogen uptake	Seed yield	Dry matter
	lb. per acre			lb. per acre		tons per acre
Uninoculated	0	7.2	0	84	744	3.0
Inoculated		9.1	5.5	181	1674	3.7
Uninoculated	60	7.8	0	86	912	3.3
Inoculated		9.2	4.9	163	1566	3.6
Uninoculated	120	8.4	0	113	984	3.6
Inoculated		9.3	4.7	173	1674	4.1

*Nitrogen applied in split application, ½ preplant, ½ at mid-vegetative stage.

†Score of 1 = yellow and 10 = dark green on October 26 at late podding.

‡Score of 0 = no nodules, 10 = many large nodules.

apart. At seeding rates of 18 to 24 seeds per foot of row the stems of the plants were thin, with consequent lodging. At plant populations above 8 plants per foot of row there was some natural thinning which increased as the population increased (table 11). Rates of seeding had no significant effect on oil and protein content.

Results were similar in an experiment conducted at Davis in 1956. Blackhawk, Hawkeye, Chippewa, and Harosoy varieties at seeding rates of 6, 12, and 18 seeds per foot in rows 30 inches apart, averaged 1614, 1614, and 1674 pounds per acre respectively. Oil and protein contents showed no consistent changes with different rates of seeding. Results from experiments in other areas of California have been about the same.

Gaps up to 8 inches in the row do not reduce yield significantly. The plants on each side of the gap compensate by branching.

Depth of seeding. Optimum depth of seeding varies considerably with date of seeding, temperature, texture of the soil, and amount of moisture present. In general, the seeds should be sown into firm, moist soil to about 1 inch or no more than 2 inches. Moist soil should be pressed closely around the seed, but it should not be packed. For example, a rubber packing wheel providing 7 pounds of pressure per square inch when seed was sown to a depth of 2 and 3 inches, has reduced stands 20 to 25 per cent. Planters should be designed to leave the surface soil loose. Ideal planting conditions are often difficult to achieve where high temperatures and low humidities prevail at planting time; as a consequence, farmers have devised various techniques to provide good conditions for the germinating seed, some of which are described below.

In the Imperial Valley success has been best with plantings 2 to 2½ inches deep into a firm, moist seedbed, if a quick furrow irrigation is given no later than 2 days after planting. The early-post-planting irrigation prevents the soil from drying out in the region of the seed and also lowers soil temperatures. Without the irrigation the temperature at a depth of 2½ inches was 80 to 100° F. An irrigation lowered temperatures 10° F. The stand was 95 per cent with an irrigation and 75 per cent without it.

In the San Joaquin Valley a technique used for cotton has been successful with soybeans. Rough beds are put up and a furrow irrigation provided before planting. When the soil is dry enough to work the beds are reshaped and soybeans planted immediately, usually with one machine. In this way the top of the bed is very moist and germination occurs quickly. In June (when high temperatures prevail) an irrigation within 2 days after sowing will improve stands.

Inoculation. As a general rule, soybean seed should be inoculated with *Rhizobium* bacteria of the type required especially for soybeans. It is an absolute necessity that the seed be inoculated the first time the crop is sown in a field, and it is usually advisable to inoculate again if more than a year has passed since the last time soybeans were grown. Because soybean inoculum is not widely used regularly in California, arrangements for its purchase and delivery should be made at the time of seed purchase.

Inoculum usually appears as a dry black dust, which is mostly organic matter. A special southwest (SW) inoculum was developed for the Imperial Valley by mixing seven of the strains which gave the best nodulation and plant response in that area (Abel and Erdman, 1964). The Southwest inoculum has been satisfactory elsewhere in California, although it has not been compared critically with inoculum developed for other areas, except in the Imperial Valley.

Only fresh inoculum should be used, and it should be stored in a cool place prior to use. Inoculum stored in a cool place for a year or more, or subjected to temperatures above 80 to 90° F for 10 to 12 hours, or left uncovered in bright sunlight for even a short time, will be nonviable. Therefore only a limited amount of seed should be inoculated at one time. This may be done by sprinkling ¾ to 1 pint of water on 60 pounds of seed in a washtub; the recommended amount of inoculum is then added and stirred until all seeds are almost black with inoculum. Because the water makes the seed coat soft,

Nodulation patterns of soybean roots. Left pair: no nodulation. Center pairs: limited nodulation after seed inoculation. Right pair: general nodulation from Rhizobium in soil before planting.

seed is placed in the planter boxes in small amounts and sown immediately. Inoculated seed should be kept cool and covered with a damp cloth. If inoculum is applied as a dust to dry seed, the amount should be doubled.

Roots should be examined about 2 weeks after the seedlings emerge, to see whether small nodules are present. Lift the roots and soil carefully with a shovel and wash the soil away. If the bacteria are in the soil at seeding time, nodules will be distributed over all of the surface roots. If the bacteria are not present in the soil and seed inoculation is the only source of the *Rhizobium,* nodulation will be abundant only in the region of the germinated seed. Nodules that furnish nitrogen to the plant appear pink when sliced open; ineffective nodules are white. As few as three or four large nodules will be adequate for good growth. If inoculation fails, and no nodules are found, about 80 pounds of nitrogen should be applied promptly as a side dressing.

The benefits of inoculation will depend on the level of soil fertility. In an experiment in the Imperial Valley on soil with low levels of available nitrogen, inoculation nearly doubled yields. Even with applications of nitrogen fertilizer at 60 and 120 pounds nitrogen per acre, yields were much increased by inoculation (table 12).

On fertile soil at Davis where yields have varied between 1600 and 2000 pounds per acre without nodulation, inoculation had little or no beneficial effect on yield in experiments conducted in 1955, 1956 and 1957. This was true whether comparisons were made with or without the addition of nitrogen and phosphorus fertilizer. In those experiments inoculation did not affect oil and protein contents in a consistent manner but generally lack of nodulation results in a higher oil and a lower protein percentage compared with beans from

Table 13

EFFECT OF NITROGEN FERTILIZATION AND DIFFERENT INOCULATION PROCEDURES ON NODULATION, YIELD, AND OIL AND PROTEIN CONTENT OF SOYBEANS, DAVIS, 1957

Rhizobium seed treatment	Nitrogen applied	Nodulation*	Yield			Oil content†			Protein content†		
			Chippewa	Blackhawk	Average	Chippewa	Blackhawk	Average	Chippewa	Blackhawk	Average
	lb. per acre		*lb. per acre*			*per cent*					
None	0	0	1890	2058	1974	16.2	14.7	15.4	39.7	40 2	40.0
Dry	0	6	1650	2178	1914	16.6	17.3	17.0	40.5	40.1	40.3
With water	0	8	1674	2028	1851	16.1	17.0	16.6	40.5	39.4	40.0
Water and honey‡	0	9	1812	2208	2010	17.3	15.3	16.3	40.9	40.4	40.6
Water and honey‡	40	5	1698	2244	1971	17.2	14.6	15.9	40.4	40.0	40.2
Water and honey‡	80	5	1560	2202	1881	17.4	17.5	17.4	41.4	40.3	40.9

*Score of 0 = no nodules, 10 = many large nodules.
†Basis 10% moisture.
‡10 to 1 by weight.

well-nodulated plants. In 1957, the addition of nitrogen fertilizer depressed nodule formation, and the addition of honey to the inoculating solution had no appreciable effect (table 13).

At Davis in 1955, several strains of *Rhizobium* were tested for their ability to produce nodules on the Lee variety. In the absence of inoculation no nodules were produced, plants were light green in color, and 112 days after seeding the yield of hay was 7940 pounds per acre with a protein content of 11.6 per cent. All *Rhizobium* strains produced nodules, and plants were dark green. Where a composite rhizobial strain was used, yield of hay was 7760 pounds per acre, and protein content 14.6 per cent. Apparently, good nodulation can increase protein content of the hay without affecting yield.

An experiment at the West Side Field Station illustrated the relationship between the application of nitrogen and nodulation. Different rates of nitrogen fertilizer (ammonium sulfate) were applied before sowing, at flowering, or at both times. A barley crop was harvested just

Table 14

MEAN NUMBER OF NODULES PER SOYBEAN PLANT AFTER FERTILIZATION WITH AMMONIUM SULFATE AT DIFFERENT RATES AND DIFFERENT TIMES, WEST SIDE FIELD STATION, FIVE POINTS, 1968

Applications of nitrogen		Mean number of nodules per plant		
Time	Pounds per acre	Straw burned	Straw not burned	Nitrogen rate average*
Preplant	0	17.5	15.4	16.5
	50	5.2	2.2	3.7
	100	1.8	6.8	4.3
	150	2.2	4.4	3.3
Preplant application average		6.7	7.2	6.9
Preplant + flowering	0 + 0 = 0	7.9	23.2	15.6
	0 + 50 = 50	7.9	19.0	13.5
	50 + 50 = 100	5.7	9.4	7.6
	50 + 100 = 150	1.5	8.6	5.1
Split application average		5.8	15.1	10.4
Flowering	0	12.0	24.6	18.3
	50	17.4	21.2	19.3
	100	13.5	21.8	17.7
	150	4.4	15.2	9.8
Flowering application average		11.8	20.6	16.3

*Differences due to *time* of application significant at 5% level; differences due to *rate* of application significant at 1% level.

before seeding the soybeans. On one-half of the area the barley straw was burned. On the other half of the area the straw was shredded and left on the ground.

Applications of 50 or more pounds of nitrogen before planting reduced the number of nodules (table 14). Delayed application of nitrogen was associated with significantly higher nodule counts. However, applications of 150 pounds of nitrogen at flowering time also reduced the number of nodules. Burned and unburned areas were not significantly different in nodulation (Beard and Hoover, 1971).

Fungicidal seed treatment. Where good quality seed with a high germination is used there has been little or no benefit in California tests from treating the seed with a fungicide. If poor seed is used, however, seed treatment has resulted in better stands. Most seed-treatment chemicals are toxic to *Rhizobium* bacteria. Thus, they can reduce the effectiveness of seed inoculation, but when used at recommended rates they have no effect on *Rhizobium* bacteria already present in the soil. Where it appears that both fungicidal seed treatment and inoculation are essential, best results have come from applying the fungicide first to the seed, followed by the *Rhizobium,* with planting following shortly thereafter. Consult the current pest control guide for recommended chemicals and rate to use.

WEED CONTROL

B. B. Fischer, W. A. Harvey

Weed control is essential to economical soybean production. Weeds not only compete for moisture, nutrients, and space but also serve as hosts to insects and disease organisms which can damage the crop. Weed control is the major cost item in crop production in many soybean-growing areas, and numerous investigators have demonstrated the harm that annual weeds have on the growth and yield potential of soybeans.

Weedy fields were subject to yield reduction, delayed maturity, increased lodging and poor harvesting conditions. Studies also showed that plant height, maturity, number of pods, seeds per pod, and seed weight were adversely affected by weeds. For further background on weed control in soybeans consult the following references (Burnside and Colville, 1964*a,b;* Kust and Smith, 1969; Peters, *et al.,* 1959; Peters *et al.,* 1965; Ray, 1961; Staniforth and Weber, 1956; Staniforth *et al.,* 1963; Wax and Pendleton, 1968; Wiggins, 1939).

Weed species

Most research on soybean weed control in California was done in the San Joaquin Valley. Weeds generally the most troublesome in that area include:

Redroot pigweed
Amaranthus retroflexus L.
Lambsquarters
Chenopodium album L.
Barnyardgrass
Echinochloa crusgalli (L.) Beauv.
Prickly lettuce
Lactuca Serriola L.
Annual sowthistle
Sonchus oleraceus L.
Lance leaf groundcherry
Physalis lanceifolia Nees.
Hairy nightshade
Solanum sarrachoides Sendt. ex Mart.
Cocklebur
Xanthium strumarium L. var. *canadense* (Mill.) T. & G.
Common sunflower
Helianthus annuus L.
Tall morning glory
Ipomoea purpurea (L.) Roth.
Tolguacha
Datura meteloides A. D.C.
Potato family
Solanaceae
Puncture vine
Tribulus terrestris L.

Principles of weed control

A good weed-control program includes the following:

- Proper selection of a field free of perennial weeds.
- Good seedbed preparation to facilitate uniform planting and later cultivations.
- Proper planting to ensure uniform emergence and allow early cultivation.
- Proper row spacing (rows 30 inches or narrower offer greater weed competition).
- Adequate plant population within the row (close spacing of soybeans in the row encourages rapid growth).
- Proper fertilization and irrigation to ensure a vigorously growing crop that competes strongly with weeds.

Briefly stated, weed control must be an integral part of the entire production or management system to be effective.

Mechanical weed control

An effective method of weed control in soybeans is timely cultivation with properly adjusted tools. Emergence and rapid growth of weeds in the planted row can offer severe and early competition.

Shallow working of the soil with rotary hoes, with tines reversed, will control weeds in their seedling stage of growth. Reversed disk-hillers and bed knives can also be used effectively when the beans are small, and breaking up the top ½ to 1 inch of soil will also kill weeds.

Finger-type weeders properly adjusted to operate under a shallow layer of soil can be used to remove seedling weeds, especially grasses, from the planted row when beans are well established (2 inches or taller). Rubber weeders similar to finger-type weeders but made of rubber can also be used; both these devices work best in lighter soils. Sectioned rolling cultivators are found to be effective and versatile cultivating tools where beans are on beds or flat-planted in rows.

Effective mechanical weed control depends on timeliness of operations. The younger the weeds the more easily they are dislodged and destroyed by cultivation. Adverse weather conditions or irrigation schedules can make effective mechanical weed control difficult or impossible because soil is too wet or too dry. Selective herbicides have greatly improved weed control in soybean fields.

Chemical weed control

Investigators in the Midwest states have found that residual pre-emergence herbicides are as effective as timely shallow cultivations, and are superior when rainfall delays cultivation.

Most published data summarize soybean weed control research conducted in areas where natural precipitation follows soybean planting; under these conditions surface applied pre-emergence herbicides performed effectively. Herbicides registered for use in soybeans are shown on page 33; this list will change as new herbicides are developed and older ones abandoned.

To obtain effective weed control from surface application the herbicide must be leached by water into the soil where weed seeds germinate. Rain or sprinkler irrigation is effective for leaching the herbicide, but furrow irrigation has not been successful. In California the weed control obtained with surface-applied pre-emergence residual herbicides has been erratic and unpredictable.

California studies 1966–67

During the 1966 and 1967 growing seasons selected herbicides were evaluated under varied methods of land preparation, soil incorporation, and furrow and sprinkler irrigation. These studies further demonstrated that incorporation of herbicides is essential for effective weed control under furrow irrigation. Incorporation with power-driven rotary tillers gave the most effective control. Sectioned rolling cultivators gave as effective control when two passes were made over the same area (in opposite directions) as did incorporation with disks to a depth of 3 to 4 inches prior to listing.

Tolerance of soybeans to the herbicides used was equally good regardless of the incorporation tools employed. Vernolate, chlorpropham, diphenamid, and a combination of diphenamid and trifluralin gave the most effective volunteer barley control. Weed control with vernolate was

TABLE 15
EFFECT OF DIFFERENT HERBICIDES ON NUMBER OF VOLUNTEER BARLEY PLANTS AND SOYBEAN PLANTS COMPARED WITH UNTREATED PLOT, WEST SIDE FIELD STATION, FIVE POINTS, 1966*

Herbicide	Application rate‡	Effect on volunteer barley			Effect on soybeans
		Number of plants per plot	Per cent of untreated plot§		Number of plants
			On bed	In furrow	
Trifluralin† / Chlorpropham†	0.75 / 3.0	11	9a	24a	106
Chlorpropham	4.0	3	17ab	57b	87
Vernolate	3.0	4	19ab	90bc	90
Amiben®	3.0	8	67cd	100c	94
Untreated	—	28	100e	100c	110

*Harosoy 63 soybeans sown July 28 after a crop of California Mariout barley. Barley straw and broadcast herbicide applications incorporated by discing. Beds made on 30-inch centers in July, 1966.

†Trifluralin and chlorpropham were used in a combination treatment at rates shown by first two figures in the next column.

‡Active ingredient in pounds per acre.

§Values followed by the same letter do not differ significantly. ($P = <0.05$) Duncan's multiple range test.

markedly better with incorporation by power-driven rotary tillers.

Early growth of soybeans was retarded in areas treated with chlorpropham, alone or in combination with trifluralin (table 15). Vernolate also caused early growth retardation, plus some deformity (fusion) of the leaflet on the first true leaves. The retardation caused by these herbicides was short-lived; a month following crop emergence it was not discernible. Amiben®, DCPA, and propachlor failed to give adequate volunteer barley control. As expected, residual control was short with chlorpropham and vernolate. Five to six weeks after treatment, summer annual weeds (primarily pigweeds, lambsquarters, and barnyardgrass) were germinating and growing in the treated areas.

California Studies, 1968–69

It was envisioned that soybeans in the San Joaquin Valley will be grown in a double-cropping system following barley or, possibly, wheat. Attention was therefore focused on controlling volunteer barley. Varied methods of soil preparation were employed, with emphasis on minimum soil manipulation following barley harvest. Chlorpropham and diphenamid were the only herbicides used because of their effectiveness in controlling volunteer barley. The performance of these herbicides was evaluated in plots where barley stubble and straw were burned, and in unburned areas. In the unburned areas the thoroughness with which the straw and stubble were incorporated into the soil varied with the method of soil preparation (pages 19–20). The herbicides were evaluated in pre-irrigated plots and in plots where the crop was planted in dry soil and then irrigated.

Burning straw and stubble greatly reduced the volunteer barley population. Effectiveness of burning varied with the quantity of straw present and the intensity of the fire. Where straw was sparse, control was poor. Postplant surface-applied herbicides under sprinkler irrigation performed much better in the burned areas than in the straw-mulch areas. Diphenamid gave somewhat better control than chlorpropham when applied postplant and sprinkler-irrigated. The most effective control was obtained when the herbicides were incorporated $2\frac{1}{2}$ to 3 inches deep, in a 12-inch band with a power-driven rotary tiller (tables 16, 17). This method was effective in both burned and unburned areas when the barley was planted on 30-inch beds and the soil left undisturbed until the herbicide was applied and incorporated.

Chlorpropham gave somewhat better control when incorporated with sectioned rolling cultivators. Two passes over the same area, made in opposite directions, gave better control than a single pass. Where barley was planted on 30-inch beds, control was improved by working the beds with sectioned rolling cultivators once prior to herbicide application.

Emergence of seedlings was more rapid and uniform in both herbicide-treated and

Table 16

EFFECT OF HERBICIDES ON NUMBER OF SOYBEAN AND VOLUNTEER BARLEY PLANTS FOLLOWING DIFFERENT SEEDBED PREPARATIONS, WEST SIDE FIELD STATION, FIVE POINTS, 1968*

Herbicide	Application rate†	Method of incorporation‡	Number of plants§			
			Burned area		Straw-mulch area	
			Soybean	Barley	Soybean	Barley
Chlorpropham	4	Power	51	3	51	1
Chlorpropham	4	Rotary	56	4	58	2
Chlorpropham	4	None	58	30	37	6
Diphenamid	5	Power	53	16	41	15
Diphenamid	5	Rotary	56	11	53	13
Diphenamid	5	None	60	4	30	17
Untreated	—	Power	57	16	42	18
Untreated	—	Rotary	79	22	50	18
Untreated	—	None	62	19	23	7

*Wayne soybeans sown July 3 after a crop of California Mariout barley. Barley seed was broadcast and beds made on 30-inch centers in November, 1967. Barley straw and stubble was burned on half of test area, and was mulched with a flail type cotton stalk chopper on other half.

†Active ingredient in pounds per acre.

‡Power = power-driven rotary tiller operating at 2½ mph, with incorporation 2.5 to 3.0 inches deep; rotary = sectioned rolling cultivators. None = untilled, surface application.

§Counts were made in a 6-inch band 8 feet long over center of bed.

untreated areas when the soybeans were planted in dry soil and irrigated up. Uncontrolled volunteer barley attained a height of 12 to 20 inches before heading out, and produced 6 to 18 seeds per head. The effect of this competition on soybean growth and vigor varied with the density of the barley population. Timely cultivations can control volunteer barley unless repeated irrigations are needed. After secondary roots develop on the barley removal is difficult, especially from the planted row.

California studies, 1970

Wayne variety was seeded on June 25th, and effect of the herbicides was evaluated on July 14th and 28th. Some herbicides did not injure soybeans, while others produced severe injury. There were also large differences between the effectiveness of the herbicides in controlling the volunteer

Table 17

EFFECT OF HERBICIDES ON STANDS OF VOLUNTEER BARLEY AND YIELD OF SOYBEANS FOLLOWING DIFFERENT SEEDBED PREPARATION, WEST SIDE FIELD STATION, FIVE POINTS, 1969*

Herbicide	Application rate†	Method of incorporation‡	Barley stand§		Soybean yield‖	
			Burned area	Straw-mulch area	Burned area	Straw-mulch area
Chlorpropham	4	Power	10	8	1540	1020
Chlorpropham	4	Rotary	10	8	1560	1380
Chlorpropham	4	None	35	55	1300	1460
Diphenamid	5	Power	28	30	1340	1500
Diphenamid	5	Rotary	18	38	1300	1240
Diphenamid	5	None	45	58	1560	980
Untreated	—	Power	50	93	1320	1440
Untreated	—	Rotary	53	80	1440	1240
Untreated	—	None	50	70	1160	1540

*Kent soybeans sown June 19 after a crop of California Mariout barley. Barley seed was broadcast and beds made on 30-inch centers in November 1968. Barley straw and stubble was burned on half of test area, and mulched with a flail-type cotton-stalk chopper on other half. Soybeans harvested October 25, 1969.

†Active ingredient in pounds per acre.

‡Power = power-driven rotary tiller operating at 2½ mph, with incorporation 2.5 to 3.0 inches deep; rotary = sectioned rolling cultivators. None = untilled, surface application.

§Stand of barley in per cent of a solid stand which would rate 100%.

‖Yields not significantly different.

Table 18

EFFECTS OF VARIOUS HERBICIDES ON SOYBEANS AND VOLUNTEER BARLEY, WEST SIDE FIELD STATION, FIVE POINTS, 1970

Herbicides	Application rate§	Effect on soybeans: Number of plants Aug. 14‖	Effect on soybeans: Injury evaluation Aug. 14¶	Effect on barley: Number of plants Aug. 14‖	Effect on barley: Control evaluation Aug. 28¶
Alachlor	2.0	23.6a	0.6	8.6b	6.6
Alachlor	4.0	22.3a	0	8.3b	6.6
Chloroxuron	2.0	21.3a	0	9.6b	2.3
Chloroxuron	4.0	19.3a	1.0	4.3b	5.6
Norea	2.0	15.0b	0.6	17.3d	0
Norea	4.0	18.6a	0	13.0c	3.0
VCS438	2.0	14.3b	6.0	8.3b	6.3
VCS438	4.0	6.0c	7.6	6.3b	7.0
Diphenamid	6.0	20.3a	0	3.6a	9.0
Trifluralin*	0.25	19.0a	2.6	7.0b	7.6
Diphenamid*	4.0				
Chlorpropham	4.0	18.0a	1.6	3.3a	9.0
Chlorpropham†	2.0	21.0a	0.6	3.3a	
Trifluralin†	0.75				9.0
Chlorpropham‡	2.0	18.0a	2.0	4.0a	
SD30187‡	0.75				9.0
SD 3018	0.75	15.0b	1.6	15.6c	2.3
ER 5461	0.75	19.3a	1.3	5.6a	4.6
Untreated	—	19.6a	0	23.0d	1.3

*Trifluralin and diphenamid were used in a combination treatment at rates shown in adjacent column.

†Chlorpropham and trifluralin were used in a combination treatment at rates shown in adjacent column.

‡Chlorpropham and SD 30187 were used in a combination treatment at rates shown in adjacent column.

§Active ingredients in pounds per acre.

‖Counts were made in a 6-inch band 4 feet long over center of bed. Values given are from two areas in each plot for three replications, and are estimates of the average number of plants in 4 feet of row. Values followed by the same letter do not differ significantly (P = <0.05) Duncan's multiple range test.

¶Soybean injury and barley control based on 0 to 10 scale. 0 = no injury or control, 10 = severe injury or perfect control.

barley (table 18). Diphenamid, chlorpropham, and chlorpropham plus trifluralin produced the least injury to the soybeans with the most effective control of volunteer barley.

Selection of herbicides

Annual weeds, including volunteer barley, can be effectively controlled in soybeans in California by properly selected herbicides and by one or two timely cultivations. However, no single herbicide registered for use in soybeans will control all weeds found infesting cultivated land in California. Therefore, the soybean grower must know what the weed infestation is before he can select the most effective herbicide or combination of herbicides.

In selecting herbicides for use in soybeans, their residual properties must be carefully considered. Because soybeans have a relatively short season, consideration of long residual herbicides such as nitralin or trifluralin must take into account the tolerance of crops to be planted following soybeans. This is especially important in a double-cropping system.

Performance of selected herbicides

Preplant-incorporated. Nitralin and trifluralin effectively controlled all summer annual grasses and many broadleaf weeds. Both herbicides must be incorporated into the soil to a depth of $1\frac{1}{2}$ to 3 inches. Deep incorporation should be avoided because both herbicides retard the secondary root development of soybeans.

Disk harrows have been used for effective incorporation of nitralin and trifluralin prior to bedding, and power-driven rotary tillers and sectioned rolling cultivators were used effectively in listed fields. With the latter, two passes over the same bed in opposite directions gave better incorporation and weed control than did a single pass. With incorporation in pre-

bedded fields, treated soil must not be removed from bed-tops in the planting operation.

Nitralin or trifluralin will not control volunteer barley, wild lettuce, sowthistle, groundcherry, nightshade, cockleburr, wild sunflower, or annual morning glory, (all summer annuals commonly occurring in California), nor will they control tolguacha, a perennial.

Chlorpropham incorporated prior to planting controlled volunteer barley effectively but was relatively ineffective on broadleaf weeds.

Diphenamid incorporated preplant effectively controlled all summer annual grasses, including volunteer barley and some broadleaf weeds. Diphenamid pro-

HERBICIDES REGISTERED FOR USE IN SOYBEAN PRODUCTION

Common and trade names	Chemical name	Methods of use
Amiben (Amiben®)	3-amino-2,5 dichlorobenzoic acid	Pre-emergence
CDAA (Randox®)	N,N-diallyl-2-chloroacetamide	Pre-emergence
Chloroxuron (Tenoran®)	3-[p-(p-chlorophenoxy)phenyl]-1,1 dimethylurea	Post-emergence
Chlorpropham (CIPC®)	isopropyl m-chlorocarbanilate	Pre-emergence
Dalapon (Dowpon®)	2,2-dichloropropionic acid	Preplant (18 days prior to planting)
DCPA (Dacthal®)	Dimethyl tetrachloroterephthalate	At time of seeding
Diphenamid (Dymid® or Enide®)	N,N-dimethyl-2,2-diphenylacetamide	Pre-emergence
Dinoseb (DNBP®)	2-sec-butyl-4,6-dinitrophenol	Pre-emergence or postemergence
Linuron (Lorox®)	3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea	Pre-emergence or post-emergence
Naptalam (Alanap® or NPA®)	N-1-naphthylphthalamic acid	Pre-emergence
Nitralin (Planavin®)	4-(methylsulfonyl)-2,6-dinitro-N,N-dipropylaniline	Preplant (soil incorporated) or pre-emergence
Propachlor (Ramrod®)	2-chloro-N-isopropylacetanilide	Pre-emergence (seed crop only)
Trifluralin (Treflan®)	a,a,a,-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine	Preplant (incorporated)
Vernolate (Vernam®)	S-propyl dipropylthiocarbamate	Preplant or pre-emergence or post-emergence
2,4-DB	4-(2,4-dichlorophenoxy) butyric acid	Post-emergence
MCPB	4[(4-chloro-o-tolyl)oxy] butyric acid	(directed spray)

vided 5 to 6 weeks of control but failed to control weeds in the potato family.

Vernolate provided excellent control of all summer grasses and many broadleaf weeds, including groundcherry, wild lettuce, and sowthistle. Vernolate has short residual properties, giving 4 to 5 weeks of effective control.

Pre-emergence application. Chlorpropham applied on the surface of the soil under sprinkler irrigation gave effective control of volunteer barley. Control was less effective when sprinkler irrigation was delayed more than 1 day following herbicide application.

Diphenamid gave somewhat better weed control when incorporated into the soil prior to planting, but control was acceptable from pre-emergence application under sprinkler irrigation.

Post-emergence or lay-by treatment. Linuron or chloroxuron applied as a post-emergence spray to beans and weeds was effective in controlling seedling broadleaf weeds and grasses.

2,4-DB and MCPB were evaluated for the control of puncture vine and other summer annual broadleaf weeds. Directed sprays effectively controlled the weeds without damaging the beans.

Propachlor, naptalam, CDAA, and amiben are registered for use in soybeans, but need further evaluation under California environmental conditions and management practices.

Caution essential in using herbicides

Costs of weed control in soybean production can be minimized by judicious use of selective herbicides. To avoid crop injury and excessive residue on the harvested crop or harmful soil residue on crops planted after soybeans, follow the directions on the label carefully.

Remember—only the user can make a herbicide safe.

IRRIGATION

D. W. Henderson, R. J. Miller

Because soybeans have not been widely grown under irrigation, information on irrigation requirements and response of the crop to varied irrigation practices is largely limited to results of experiments. Tests have been conducted under only a few of the varied conditions which might be encountered. An analysis of experimental data does present a reasonably clear picture of how soybeans should be irrigated, especially in relation to requirements of other crops with which growers are more familiar. This section presents such an analysis and comparison with more commonly grown crops. To do so, we must draw freely upon work of others. We acknowledge this and express appreciation to all those who have contributed data.

Root development studies

The seedling starts growth without roots, so the ability to extract moisture from the deep subsoil depends on the rate of growth of the root system into the lower depths. Since water in the soil moves slowly to the root, the degree to which the root system permeates each small volume of soil also is an important factor in the absorption of water needed to maintain growth processes. Water-removal studies are especially important for soybeans because they are generally planted when hot, dry weather prevails and the evaporative demand is frequently high, even in early growth stages.

The effectiveness of the root system in extracting water from various depths can be determined by measuring the residual moisture of an initially moist soil at the time the crop shows visible water-deficit symptoms.

When expressed as the range of moisture available to plants, a value of 100 per cent represents no extraction; zero per cent indicates the soil is at the wilting stage. Such data are available for two soils. At Davis the soil is Yolo clay loam, a deep alluvial soil with texture relatively uniform to over 6 feet. The subsoil is open and readily penetrated by both water and plant roots.

Table 19

RESIDUAL AVAILABLE SOIL-MOISTURE DISTRIBUTION IN YOLO CLAY LOAM UNDER CHIPPEWA AT GROWTH RETARDATION (AGES 46 AND 67 DAYS) AND AT NEAR MATURITY (AGE 92 DAYS) PLANTING DATE, JULY 1, 1957

Depth	Per cent of available soil moisture remaining at various times		
	46 days	67 days	92 days
0-1 ft.	−7.7	−11	−13
1-2	−0.1	12	1.3
2-3	13	7	4.5
3-4	58	16	14
4-5	100	49	21
5-6	100	94	44
6-7	—	—	57
7-8	—	—	100
8-9	—	—	100

Visible symptoms of early stages of water deficit are difficult to detect in soybeans. Darkening of the upper foliage, which is readily apparent in common beans, is not clearly visible. Therefore, the soil was sampled for moisture as soon as slowing of growth was evident. The times selected were rather arbitrary, and this was substantiated by the fact that when irrigation was delayed for as much as an additional week the appearance of the plants did not change noticeably.

The residual soil moisture at age 46 days showed an active effective root system to 3 feet, some extraction from the 4th foot, and essentially none below 4 feet (table 19). At 67 days the zone of effective water absorption had deepened to 4 feet, but there was still no absorption from the 5 to 6 foot depth. The data for early maturity (92 days) are included to show still deeper extraction by that time.

Soil moisture extraction from Hesperia sandy loam near Shafter proved similar. In this case plants were allowed to wilt prior to soil sampling. It proved necessary to irrigate within 3 weeks after planting, but because of little water use by that time, sampling was omitted. Table 20 gives results of two subsequent samplings. In this experiment, wilting prior to each irrigation caused nearly 30 per cent reduction in seed yield. However, the data show that effective rooting depth is about 2 feet at 42 days and 4 feet or more at 70 days.

Both Yolo and Hesperia soils cause little or no retardation of root development, and the data cited indicate the inherent rooting capability of the soybean plant. In this respect it ranks rather high in comparison with other crops. It is much superior to red or pink beans, field corn, or cotton, and is at least equivalent to that of Blackeye beans (cow peas) and grain sorghum.

There is little information on effect of dense subsoil on root growth. However, an Imperial Valley test on Holtville clay, which has dense subsoil, indicates the possible magnitude. When soil water tension was 9 atmospheres at the 8-inch depth, typical estimated values of per cent available moisture during flowering and seed development were: 0 to 8 inches, 10 per

Table 20

RESIDUAL AVAILABLE SOIL MOISTURE IN HESPERIA SANDY LOAM AT WILTING AVERAGES FOR CLARK, HAWKEYE, AND ADAMS VARIETIES* PLANTED JUNE 11, 1957

Depth	Per cent of available soil moisture remaining at various times	
	42 days	70 days
0-1 ft.	−11	0
1-2	9	0
2-3	65	10
3-4	95	15

*Data of J. R. Stockton (deceased) Department of Water Science and Engineering, University of California, Davis.

cent; 8 to 16 inches, 35 per cent; 16 to 24 inches, 50 per cent; 24 to 36 inches, 90 per cent (data of George H. Abel, unpublished).

Water requirements

In irrigation planning and practice it is useful to know the rate of water loss from the cropped area by evaporation and transpiration. However, if complete information is lacking, knowledge of the time and magnitude of maximum use along with the total seasonal requirement will be valuable. Data for soybeans are limited, and estimates must be reinforced by comparison with data from other crops grown about the same time, as well as by study of climatic and plant factors influencing evapotranspiration.

The Chippewa variety at Davis, planted July 1, used 19 inches of water for the entire season. At Shafter, six irrigations estimated at 3 inches of water per irrigation, appeared to adequately supply the crop (data of J. R. Stockton, unpublished). No accounting was made of water stored in soil at planting, but this can be discounted because the first irrigation was applied very early before much water use by the crop. The peak use rate was 0.28 inch per day in early August, a value probably similar to that of other crops at the same time.

In West Side Field Station experiments, 15 inches of water applied during the cropping season produced near-maximum yields. A 12-inch preirrigation was applied before seeding. The fraction of the preirrigation water used by the crop was not measured, but could not have been more than a few inches. Thus, water use of 18 to 22 inches seems reasonable.

Data for water use at Davis have been compared with those for pink beans, blackeyes, and grain sorghum—crops commonly planted in early June. The seasonal water use for all these crops is similar, ranging from 18 to 22 inches.

Planting date probably has appreciable influence. In the July 1 planting at Davis, maximum vegetative development was not reached until late August when potential evapotranspiration is appreciably below the peak reached under full plant cover in June or July. Thus planting on June 1 might increase seasonal water use by 3 or 4 inches.

All available evidence indicates that seasonal water use for soybeans in the Sacramento and San Joaquin Valleys is 20 to 24 inches, with lower values within that range applicable to earlier-maturing varieties and late planting.

In an Imperial Valley test, estimates of water applied ranged from 28 to 39 inches including two irrigations for establishment of stand from planting and replanting. Yield differences, while statistically significant, were not great (data of George H. Abel, unpublished). On the basis of these data and comparison of climatic factors influencing evapotranspiration with those of the Central Valley, an approximate estimate of seasonal water use for the Imperial Valley is 25 to 30 inches.

Responses to irrigation treatments

Tables 21 to 28 give data on various responses to differential irrigation treatments at five locations. A wide range of soil conditions are represented, and the climatic differences between locations at Davis and Brawley are appreciable.

At Davis the tests were on Yolo soil, a deep alluvial clay loam. The available water storage capacity of the soil is moderately high (approximately 1.5 inches water per foot of soil) and the subsoil readily penetrable by roots. In Experiment Davis–1 (table 21), the treatment receiving 10 irrigations was irrigated weekly beginning 4 weeks after planting. The 2-irrigation treatment was irrigated after an observable retardation of growth but prior to wilting. The 1-irrigation treatment was watered 1 week after the first irrigation of the 2-irrigation treatment. The 3-irrigation treatment was irrigated at weekly intervals prior to flowering with no irrigations after onset of flowering. For Experiment Davis–2 (table 22), irrigation interval for the most frequently irrigated treatment was 10 to 12 days. The 2-irrigation treatment was applied at observable growth retardation.

At Five Points, the Panoche clay-loam soil is deep alluvium with high available

TABLE 21
EFFECTS OF IRRIGATION TREATMENTS ON CHIPPEWA VARIETY
PLANTED JUNE 8, 1957, EXPERIMENT DAVIS-1

Number of irrigations	Plant height	Weight of 100 seeds	Yield	Lodged
	in.	*gm.*	*lb. per acre*	*per cent*
10	42	20.0	2264	65
3	43	18.1	1988	35
2	42	17.8	2296	5
1	42	17.1	1923	3

TABLE 22
EFFECTS OF IRRIGATION TREATMENTS ON CHIPPEWA VARIETY
PLANTED JULY 1, 1958, EXPERIMENT DAVIS-2

Number of irrigations	Plant height	Pods per plant	Weight of 100 seeds	Yield	Lodged	Maturity date
	in.		*gm.*	*lb. per acre*	*per cent*	
6	37	17. 4	17. 2	1588	40	11/5
2	35	20. 5	15. 1	1712	10	10/20
0	31	15. 5	11. 6	1092	0	10/3

TABLE 23
EFFECTS OF IRRIGATION TREATMENTS ON THREE SOYBEAN VARIETIES
PLANTED MAY 26, 1966, EXPERIMENT FIVE POINTS-1

Number of irrigations	Chippewa			Clark			Wayne		
	Yield	Oil	Protein	Yield	Oil	Protein	Yield	Oil	Protein
	lb. per acre	*per cent*		*lb. per acre*	*per cent*		*lb. per acre*	*per cent*	
5	1650	19.8	48.5	1790	17.6	46.5	2060	19.7	47.6
3	1580	20.2	48.0	1580	17.6	46.2	1905	19.7	46.4
1	995	20.4	44.3	1005	21.9	42.4	1115	20.5	42.3

water storage capacity (2 inches per foot). Physical retardation of root growth is probably slight, but the salinity and boron levels are high enough to affect plant growth and possibly root development. The 5-, 3-, and 1-irrigation treatments of Experiment Five Points-1 (table 23) were applied when soil moisture levels were at approximately 50, 35, and 10 per cent available moisture at the 18-inch soil depth. A 12-inch preirrigation was applied, and treatments received respectively 22, 15, and 5 inches of irrigation water during the cropping season.

For experiment Five Points-2 (table 24), irrigations were applied at 65, 50, and 35 per cent residual available moisture at the 18-inch soil depth for, respectively, treatments receiving four, three, and two irrigations. A 12-inch pre-irrigation was applied, followed by 16.5, 14.5 and 11 inches during the growing season. Mite infestation was severe but not uniform in the area. (For additional details of these two experiments see Miller and Beard, 1967.)

The Shafter experiment (table 25) was conducted on Hesperia sandy loam of low available water storage capacity (about 0.7 inch per foot), readily penetrated by roots. The 6-irrigation treatment was irrigated at 2 week intervals, while in the 3-irrigation treatment watering was delayed until plants wilted.

Soil characteristics are not available for the site of the Corcoran Experiment (table 26). However, the soils of the vicinity are clay loams and clays with variable subsoils. The 5-irrigation treatment was first irrigated 24 days after planting and subsequently at 17, 14, and 21 day intervals.

Table 24
EFFECTS OF IRRIGATION TREATMENTS ON TWO VARIETIES
PLANTED MAY 25, 1967, EXPERIMENT FIVE POINTS-2

Number of irrigations	Clark			Wayne		
	Yield	Oil	Protein	Yield	Oil	Protein
	lb. per acre	*per cent*		*lb. per acre*	*per cent*	
4	990	19.3	47.3	1194	19.3	47.2
3	966	20.1	46.3	1110	19.0	47.7
2	624	18.9	46.2	660	19.2	46.4

The 4-irrigation treatment was watered at moderate observed water deficit, and the 3-irrigation treatment was irrigated at wilting.

The Brawley experiments were conducted on intermixed Holtville silty clay and Holtville clay. Holtville subsoils are typically dense, and soil salinity at levels of 5 to 10 mmhos per cm in the saturation extract were measured in the plot area of Experiment Brawley-1 (table 27). The plants were irrigated up and two subsequent irrigations applied before differential irrigation treatments were started at age 43 days. The irrigation regimes were classified according to soil moisture tension at 8- or 16-inch depth: *wet* if subsequent irrigations were applied at 0.3 bar soil-moisture tension; *medium* at 2 bars and *dry* at 6 bars. The irrigation regimes were varied during three periods of plant development. The first period included the remainder of the development prior to flowering, the second period was from the beginning till the end of flowering, and the third included pod formation and seed development. The 12-irrigation treatment was thus characterized as wet-wet-wet and the 11-irrigation treatment wet-dry-wet. The first 9-irrigation treatment was termed wet-dry-dry, the second 9 (9M in table 27) as medium throughout, and the 7-irrigation treatment dry throughout. Data are averages for all row spacings and in-row plant spacings.

In Experiment Brawley-2 (table 28) differential irrigation did not start until five weeks after planting, and four irrigations had been applied by that time. Subsequent irrigations were applied at 0.6, 2, and 9 bars (presumably at the 8 or 16 inch soil depth) for the 12-, 8-, and 6-irrigation treatments. Data for uninoculated treatments are not included, but data are averaged for nitrogen treatments since nitrogen produced little effect on yield.

Effect on yields and yield components

The effect of irrigation treatment is less at Davis than at any other site. The soil was moist at planting to depths well below the potential rooting depth. The root system increases in depth and in degree of proliferation, tapping new sources of water nearly rapidly enough to produce maximum yields without irrigation or rainfall. The unirrigated treatment in Experiment Davis-2 produced a very satisfactory yield (70 per cent of maximum). One or at most two irrigations produces maximum yield provided the root zone is moist at planting. The Brawley experiments illus-

Table 25
EFFECT OF IRRIGATION TREATMENTS ON CLARK VARIETY
PLANTED JUNE 11, 1957, SHAFTER EXPERIMENT*

Number of irrigations	Plant height	Yield	Lodging	Maturity date
	in.	*lb. per acre*	*per cent*	
6	53	2686	40	10/25
3	49	1926	10	10/20
LSD 5%		480		

*Data of J. R. Stockton.

TABLE 26
EFFECT OF IRRIGATION TREATMENTS ON CLARK VARIETY
PLANTED JUNE 26, 1957, CORCORAN EXPERIMENT*

Number of irrigations	Plant height	Yield	Lodging	Maturity date
	in.	*lb. per acre*	*per cent*	
5	39	1469	40	11/3
4	39	1752	10	11/3
3	36	1510	10	10/29
LSD 5%		179		

*Data of R. T. Edwards and P. F. Knowles.

TABLE 27
EFFECT OF IRRIGATION TREATMENTS ON SOYBEANS
PLANTED JUNE 6, 1954, EXPERIMENT BRAWLEY-1*

Number of irrigations†	Plant height	Yield	Weight of 100 seeds	Oil	Protein
	in.	*lb. per acre*	*gm.*	*per cent*	
12	34	1548	10.	21.8	37.2
11	–	1632	10.	21.8	39.2
9	–	1284	–	22.3	36.9
9 M	33	1398	–	22.0	38.0
7	30	1074	8.2	22.3	37.1
LSD 5%		192			

*Data of George H. Abel.
†See text for difference in two 9-irrigation treatments.

TABLE 28
EFFECT OF IRRIGATION TREATMENTS ON SOYBEANS
PLANTED JUNE 16, 1955, EXPERIMENT BRAWLEY-2*

Number of irrigations	Plant height	Pods per plant	Seeds per pod	Weight of 100 seeds	Yield	Maturity date
	in.			*gm.*	*lb. per acre*	
12	24	21.8	2.04	12.0	1722	11/4
8	26	16.8	1.98	11.8	1692	11/5
6	22	17.7	1.97	12.6	1494	11/4

*Data of George H. Abel.

trate the other extreme. The dense subsoil retards root penetration, and the root zone is effectively shallow. The requirement for frequent irrigation is increased by high soil salinity and the somewhat higher rate of transpiration. Production of maximum yields on Holtville clay apparently requires eigth to ten 3- to 4-inch irrigations. Because the soil is effectively shallow, the root zone storage is so low that preirrigation is meaningless except possibly for reducing surface salinity. Furthermore, soybeans in the Imperial Valley generally must be irrigated up.

The San Joaquin Valley tests show effects of intermediate conditions, but this is probably more determined by soil than by location. The Shafter data are representative of required irrigation for a sandy soil. The available water storage in the 4 to 5 foot root zone is only 3 to 4 inches, and six 4-inch irrigations would be needed to supply the seasonal requirement. The Five Points and Corcoran soils have moderately high storage capacity, but apparently retard rate of root penetration or growth is affected by salinity. Under these conditions, seasonal water requirement must be met by moisture in the soil at planting plus three to four irrigations. If water infiltration into soil is slow, depth of water applied per irrigation is small be-

cause plants may be damaged if water is ponded too long, and the total number of irrigations must be increased regardless of water-storage capacity and penetrability by roots.

In two experiments attempts were made to determine irrigation schedules by foliar darkening; this has been shown to be effective for common beans, but the procedure failed here because foliar darkening was too indefinite. From two experiments (Shafter, Corcoran), it is apparent that delaying irrigation until wilting reduces yields.

Yield component data were collected in only two experiments, and except for seed weight determinations, sampling and counting are so tedius that adequate sampling is rarely undertaken. However, the data indicate no major impact of irrigation practice on flowering and seed development processes under conditions where extremely severe drought is not a factor. Prolonged moderate drought late in the season does result in shriveled seed and in lower seed weight (as shown in table 21).

Although soybeans bloom over a period of nearly a month, there is apparently little tendency to remain vegetative at expense of seed production. Forcing bloom by moderate drought is suggested in the Davis-2 Experiment (table 22) where the higher number of pods per plant indicates increased seed set in the 2-irrigation treatment, resulting in higher yield. However, the yield of the most frequently irrigated treatment was lower than that of an intermediate treatment in only one other experiment (at Corcoran, table 26).

Effect on protein and oil content of seed

The constituents of major interest are protein and oil. In the three experiments in which oil and protein content were measured there were no clear over-all trends except that irrigation does not markedly influence oil and protein content. Irrigation practices that reduce yields will affect seed composition only if seed size is reduced. The data of Experiment Five Points-1 (table 23) suggest that drought slightly increased oil content and decreased per cent protein. However, no trend is detectable in other data.

Effect on lodging and maturity

More frequent irrigation often increases lodging as shown in data from several experiments. Lodging generally is not caused as much by breaking or bending of stems as by lack of support at the crown, so that lodging increases with a combination of wind and wet surface soil; more frequent irrigation thus increases probability of lodging.

In most experiments the effect on maturity was not pronounced, but the Davis-2 experiment shows that moderate but prolonged water deficits, occasioned by water extraction only from deep subsoil, can hasten maturity date substantially.

Degree of shattering was measured in some experiments. The data show that irrigation treatment had little if any influence.

As with other plants, incidence of mite infestation and injury is increased by drought conditions.

Summary

Soybeans should be irrigated in the same general manner as many other field crops which grow during the same season. They are neither especially sensitive to, nor tolerant of, drought or excess water in soil. Root development is relatively rapid and vigorous, and soybeans can effectively absorb water from soil depths of 5 to 6 feet in deep, easily penetrable soils.

The crop consumes 20 to 24 inches of water during the growing season in the central valleys and 25 to 30 inches in the desert areas of California. The portion of this quantity of water not supplied by water stored in the soil at planting must be applied as irrigation. If given less water, yields will be reduced.

The number of irrigations required to provide the necessary quantity of water depends primarily on three soil characteristics: the depth, the water storage capacity, and penetrability by roots. Experiments show that the number of irrigations required for maximum yields may range from two to twelve under varied conditions.

VARIETAL TESTING AND IMPROVEMENT

B. H. Beard, P. F. Knowles

Planting the most suitable soybean variety is of paramount importance. In past years many California farmers have been disappointed with this crop, partly because they seeded varieties that were either too early or too late for their location. Soybeans are day-length sensitive (see page 15) and available varieties have a great range of maturity. If a variety is moderately late for a particular location, only a few flowers will develop late in the season; if the variety is extremely late there will be no flowers. If a variety is too early for a location it may also produce only a few beans before it matures, or if it flowers during a period of hot dry weather it may not set many pods.

For convenience in organization and comparison, soybean varieties are arranged into groups based on the date of maturity. The maturity groups are numbered 00, 0, and I through VIII, from earliest to latest types, with differences mainly in the vegetative growth period (see page 15). In U. S. soybean-growing areas, different varieties are recommended for areas only 100 to 200 miles apart in the north-south direction.

Locations for different maturity groups

The probable area of soybean production in California extends north to south for 700 miles (the distance from Ames, Iowa to Shreveport, Louisiana), thus different varieties with a wide range of maturities will be required for satisfactory yield in different areas of the state. The potential areas of soybean production in California are somewhat discontinuous and are rather distinct in varietal requirements. Most if not all of the major varieties in the United States and many experimental lines have been tested during the 50 years tests have been conducted in California. Seed for many of the tests was supplied by the U. S. Department of Agriculture through the U. S. Regional Soybean Laboratory, Urbana, Illinois and the USDA Soybean Project, Stoneville, Mississippi. During 1967 through 1969 there were 133 different varieties and lines tested in Yolo County, 197 in Fresno County, 86 in Kings County, 23 in Kern County, and 68 in Imperial County. These tests and other sources of information have indicated there are at least four regions in California with different varietal maturity requirements.

Southern Sacramento Valley

One area of potential production is the Sacramento River Valley from Stockton northward for 50 to 100 miles. Varieties in maturity groups 0 and I have given the best yields here. Chippewa or Chippewa 64 have consistently given the best yields in Yolo County tests. Other varieties satisfactory for this area are Portage and Hark. Two new varieties not extensively tested but having promise are Rampage and Wirth.

Central San Joaquin Valley

A second potential production area extends from about 50 miles north to about 50 miles south of Fresno. In this area varieties in maturity groups II and III are required. Amsoy, Beeson, and Corsoy of Group II maturity plus Calland and Wayne of Group III maturity have produced high yields in tests in Fresno and Kings Counties. Although most of the varieties of Group IV maturity have not done well at these locations, one variety, Kent, has been one of the higher yielding varieties in these tests.

Southern San Joaquin Valley

A third area of potential production is roughly 50 miles north to 40 miles south of Bakersfield. Varieties of Groups IV, IVS, or V maturity do best in this area. Calland a variety of Group III maturity did well in one test. Clark 63, Cutler, and Kent have produced the highest yields in limited tests at the USDA Cotton Research Station near Shafter. Hill, Dare and York of Group V maturity have not been tested but would

appear to have some promise for this region.

Desert areas south of the Tehachapi Mountains

The fourth area of potential soybean production is any farming region south of the Tehachapi Mountains. Varieties of maturity Groups VI and VII seem best for this region. Lee, Hood, Pickett and Davis of Group VI maturity have produced the highest average yields in tests in Imperial County. Bragg and Semmes of Group VII maturity have been slightly lower in yield. Frio, a variety adapted for many areas in Arizona has not done well in Imperial Valley tests probably due to the difficulty in obtaining adequate stands. It appears the poor stands are due to salt sensitivity during the germination stage. Cajeme, a new variety grown in Mexico should be tested in this area.

Yields

Experimental yield tests of soybeans have shown that yields, even from a single variety, may be extremely variable and may range from complete failure to over 3,000 pounds per acre at some locations. Generally, yields of all varieties in any one group under test are either high or low at any one location in any one year. It is not known why there is such extreme variation in yield from year to year or location to location.

Higher yields are common in the second season if soybeans follow soybeans on the same field. This is probably due to earlier establishment of an effective symbiotic relationship between the bacteria and the plant if the proper *Rhizobium* are distributed throughout the soil. However, even on fields where well-nodulated soybeans have previously grown it is advisable to inoculate the seed before planting, because the bacteria may not survive from one season to another in our hot dry soils.

Representative yields for a few selected varieties in each of the maturity groups are shown on page 43. These and similar data from other varieties have been used to determine varieties that might be appropriate for each area of production in California. Yields indicate that on the average about 2,000 pounds of beans per acre could be expected in most areas if the crop is well managed from seedbed preparation through harvest. The varieties that have produced the highest yields in experimental plots are included here as information for those who are considering an experimental commercial planting of the crop.

Yield data for California have been obtained using introduced varieties developed for other specific areas. Usually, variety adaptation to a given environment results in highest yields and thus it seems possible that varieties developed especially for use in California might result in higher yields than those obtained with introduced varieties. However, California cost of production studies have shown yields approximately double those obtained in past California yield tests would be needed to make soybeans competitive with other crops that can be grown during the same season.

An analysis of the situation provides some optimism. California yield tests have shown that soybean production potential here is similar to that of the Midwest. The average yield in Illinois for example is about 2,000 pounds per acre, but a few growers are routinely producing 3,500 to 4,000 pounds per acre and yields in some instances have exceeded 5,000 pounds per acre. This level of production would be profitable on high-priced California irrigated land if we can establish the combination of cultural practices and germ plasm that will produce such yields here. Varietal adaptation to the California environment would undoubtedly contribute something toward higher yields.

The varietal agronomic characteristics that must be improved for profitable production in California are: higher and more stable yields, a non-shattering pod, and spider mite resistance or tolerance. Other characteristics needing some improvement are: stiff stalks that do not lodge, plants that shed their leaves at maturity, boron tolerance or resistance, salt tolerance or resistance, and better seed quality.

A varietal improvement program even with a crop that is widely grown locally rarely can yield an improved variety in less than 10 years of plant breeding effort. Because soybeans need major changes in three important characteristics, and small changes in several other characteristics, it

AVERAGE YIELDS (POUNDS PER ACRE) OF THE MOST PROMISING SOYBEAN VARIETIES AT VARIOUS LOCATIONS IN CALIFORNIA FOR YEARS 1967 THROUGH 1969

Varieties	Yolo County*	Fresno County†	Kings County‡	Kern County§	Imperial County‖
Group 00					
Flambeau	1068	1047	1573		
Portage	1318	1128	1947		
Group I					
Chippewa 64	1098	1029¶	1999¶		
Hark	1110	1181¶	2293¶		
A-100		1058¶	2201¶		
Group II					
Amsoy	1080	1278	2253	887	
Beeson	1002	1298	1384**	1032	
Corsoy	1372	1468	2132	869	
Group III					
Calland		1344	2660**	2403	
Wayne		1273	1330	1098	
Group IV					
Clark 63		1039	1716	1759	
Cutter		1216	1890	1974	
Kent		1373	2334	1772	
Group V					
Coker 240					2109¶
Dare					1523¶
Hampton 266					2843¶
Group VI					
Davis					1931
Hood					1627
Lee					1569
Pickett					1646
Group VII					
Bragg					1409
Semmes					1201
Group VIII					
Hampton					1559
Hardee					1288

* Tests at the University of California Experimental Farm, Davis. Three-year average for 1967, 68, and 69.
† Tests at the West Side Field Station, Five Points. Three-year average for 1966, 68, and 69.
‡ Tests at J. G. Boswell Co., Corcoran. Two-year average for 1966–67.
§ Tests at the Cotton Research Station, Shafter. One-year test, 1968.
‖ Tests at the Southwestern Irrigation Field Station, Brawley. Two-year average 1966–67.
¶ One year only 1966.
**One year only, 1967.

is unrealistic to believe varieties suitable for California conditions could be developed in less than 10 to 15 years even with adequate funding. The breeding program should include cultural practices designed to maximize yield potential.

All present varieties shatter in hot, dry, or windy weather. Rain on dry pods followed by hot, dry, or windy weather seems to increase the problem. There are varietal differences in the amount of shattering: Clark 63, Lee, and Bragg seem to shatter less than most other varieties and crosses of these and other varieties might increase the level of shatter resistance. Shattering is also known in other soybean production areas, but with higher humidity in these areas the problem is usually less severe.

Spider mite tolerance or resistance is an important requirement for successful production of soybeans in most of California. Although chemical protection is possible, the cost is prohibitive for a low income crop. The screening program described on

pages 48 to 50 has identified lines that have spider mite resistance. This resistance, though discovered in the greenhouse, has held up in the field. It may now be possible to develop lines with a usable level of spider mite resistance and other necessary characteristics for a commercial variety.

Stiff stems that do not lodge, leaves that fall off at maturity without the need of a frost, and pod development high enough on the stem to be harvested with a combine, are necessary for a successful variety. The present varieties are generally suitable but improvement in each characteristic would be desirable, and improved lodging resistance may be essential if 4,000 pounds per acre yields are obtained.

At present diseases are of minor importance in California, but if a large acreage of soybeans were grown here over a period of years, disease would no doubt become more important. Disease resistance would then become an important objective in a varietal improvement program.

SPIDER MITES AND INSECTS

E. C. Carlson

Spider mites

Experience over several years has shown that in California the most serious economic pest of soybeans is the spider mite. Entomological research since 1966 has therefore dealt with control of mites and mite damage.

The species of spider mites found primarily responsible for soybean damage are the two-spotted mite, *Tetranychus urticae* (Koch), and the Pacific spider mite, *T. pacificus* McG. Mites feed by sucking juices from the plant, mostly from the underside of the leaves. They can build up popula-

White spots (stippling) on leaves are caused by moderate infestation by red spider mites.

tions of over a thousand mites per leaflet. They cause a white-stippled type of injury. With high populations or prolonged feeding the leaves turn yellowish and then brown, and drop prematurely. Defoliation reduces seed yields, significantly, particularly if it occurs early.

Each female spider mite lays 50 to 60 eggs on the leaves; eggs hatch in about 3 days. The young reach maturity in 10 to 12 days, and in summer the adults live 1 to 2 weeks. Adults hibernate in winter in crevices, trash, weeds, under bark, and in the soil. There are many generations during a year, depending upon climate (principally temperature and humidity), which actually determines the length of each life cycle and the number per season. These mites prefer a dry climate, warm to hot, and build up speedily when the photoperiod is long and nutrition is satisfactory. They become more severe on plants closely spaced and irrigated infrequently, as this results in greater moisture stress, lower humidity, a decline in plant nitrogen levels, and higher temperature—all factors favoring spider mites.

Dust appears to aid mite development and increase plant damage, although research has indicated only that dust may act as a pollutant adding to plant stress. Mite numbers are decreased by many insect and mite predators in some areas and on most crops, especially if left untreated by chemicals. These predators generally build up too late to prevent plant damage by the mites, for they do not effectively decrease mite numbers until late summer or fall. Mites are web-spinning, live in and under their webbing, and migrate to adjacent plants and fields via air currents or wind when under population stress.

Research has included: (1) an inquiry into the feasibility of controlling mites with chemicals; (2) a correlation of plant damage with mite numbers; and (3) a search for and evaluation of resistant varieties.

Chemical control of mites. Essentially all this research has been done at the University of California at Davis and the West Side Field Station, near Five Points. Plots have been of various dimensions, but rows have always been 30 inches apart. Plants were on raised beds, with irrigations supplied in furrows between the beds.

Every effort was made to have heavy mite populations in the test area. Varieties Chippewa and Clark, both known to be susceptible, were used. Abundant untreated soybean material was provided, and on occasion mite-infested leaves were introduced into the test areas prior to treatments.

Spray applications were made with an experimental back-pack sprayer (pressurized with CO_2). The spray was applied at 18.9 gallons per acre at a pressure of 60 pounds per square inch. Granular side dressings were chiseled in 5 to 7 inches from the rows and 5 to 6 inches deep.

Mite infestations were measured by taking 20 leaflets at random from each plot and storing them in wide-mouthed pint jars in a refrigerator at 41°F. Two mite counts were made on each leaflet in areas ½ inch in diameter. A 6-inch strap hinge with a drilled ½-inch hole close to the base of one side of the hinge and another up in the center of the same side was used. Soybean leaflets were then placed, base first, between the halves of the hinge up to the joint. Counts were quickly made of the live mites in each hole or "window" under a binocular microscope at 12 power.

Where a single acaracidal spray application was used, Kelthane® gave the best control of mites (tables 29, 30); two applications of Trithion® gave about the same degree of control. Mite reduction was very good from a 2-pound-per-acre phorate (Thimet®) granular treatment sidedressed into the soil a month after planting (tables 29, 31). Migration of mites from untreated plots in such experiments give data that understate the actual control achieved.

Where mite counts were reduced by acaracides at the West Side Field Station in 1966 and 1967, seeds were larger and yield of seed much greater than in untreated plots (tables 29, 31). At Davis, mite control with Kelthane® and Temik® increased yields about 25 per cent in 1966 and 1967 (tables 30, 32). Rank growth of the soybeans and high humidities under the leaf canopy limited mite buildup. In all of these experiments the yield of treated plots would have been much greater in the

TABLE 29

DATA FROM A TEST OF FOLIAGE SPRAY AND GRANULAR SIDE DRESSING USED TO CONTROL MITES ON THE CHIPPEWA VARIETY, WEST SIDE FIELD STATION, FIVE POINTS, 1966*

Treatment and number of applications	Per cent reduction of live mites†					Average number of mites‡	Yield§	Weight per 100 seeds§
	foliage spray						*lb. per acre*	*gm.*
	(7)	(14)	(21)	(28)				
Trithion®, 1 (carbophenothion)	84	76	41	0		10b	272b	6.5c
Trithion®, 2 (carbophenothion)	71	84	86	0		5a	484a	7.5bc
Tedion®, 1 (tetradifon)	92	81	67	0		7a	318b	6.8c
Kelthane®, 1 (dicofol)	91	86	78	0		4a	476a	8.0ab
Morocide®, 1 (binapacryl)	45	55	0	0		19c	115c	6.0cd
	granular side dressing							
	(9)	(16)	(23)	(30)	(42)			
Di-Syston®, 1 (disulfoton)	16	2	23	0	0	26d	88c	5.6cd
Thimet®, 1 (phorate)	15	46	89	71	43	8ab	580a	8.8a
No treatment	—	—	—	—	—	30e	58c	5.3d

*Sown May 25; foliage sprays applied July 15 and July 26 at 1 lb. active ingredient per acre in 19 gal. H_2O/A at 60 psi; side dressing of 10% granular material at 2 lb. active ingredient per acre chiseled into the soil 5 inches deep 5 inches from the plants on July 6 and irrigated 2 days later.

†Numbers in parentheses are days after treatment.

‡Average number of mites from all counts during test period. Values are estimates of the number of mites in an area 1/2 inch in diameter (0.1936 sq. in.).

§Values followed by the same letter do not differ significantly (P = <0.05) Duncan's multiple range test.

TABLE 30

DATA FROM A TEST OF FOLIAGE SPRAYS APPLIED TO CHIPPEWA VARIETY, DAVIS, 1966*

Treatment	Application rate†	Reduction in live-mites and days after treatment				Yield‡
		2	7	14	21	
		per cent				*lb. per acre*
Kelthane® (dicofol)	1.0	36	77	93	92	1,205a
Trithion® (carbophenothion)	1.0	69	68	84	83	986b
Cygon® (dimethoate)	0.5	67	51	71	—	—
(diazinon)	1.5	55	38	34	—	—
No treatment	—	—	—	—	—	913b

*Sown June 8; sprays applied August 23 at 60 pounds per square inch in 19 gal. H_2O per acre.

†Active ingredient in pounds per acre.

‡Values followed by the same letter do not differ significantly (P = <0.05) Duncan's multiple range test.

absence of migration of mites from untreated plots. Results in 1968 at Davis showed that treatment with phorate at both planting time and as a seedling side-dressing greatly improved mite control and seed yield from Chippewa.

Two acaracidal applications appear to be optimum, and cost 4 to 8 dollars apiece (1972 prices) depending on the material used, the amount needed per acre, and the type and cost of application. Despite good mite control in studies conducted to date, yields have still been low.

The pesticides tested are not yet ap-

TABLE 31

DATA FROM A TEST OF FOLIAGE SPRAY AND GRANULAR SIDE DRESSING APPLIED TO CLARK VARIETY, WEST SIDE FIELD STATION, FIVE POINTS, 1967°

Treatment	Application rate†	Per cent reduction of live-mites‡					Number of mites§ ‖	Yield
		foliage sprays						*lb. per acre*
		(4)	(11)	(18)				
Kelthane® (dicofol)	1	69	92	73			10a	24
GS-19851	1	49	83	73			11a	1
Supracide®	1	55	92	69			11a	1
Morestan®	1	56	80	62			15a	3
No treatment		—	—	—			46b	0
		granular side dressing						
		(14)	(21)	(28)	(35)	(49)		
Thimet® (phorate)	2	18	34	66	82	87	9a	79
Thimet® (phorate)	4	27	48	67	84	89	9a	275
Temik®	2	49	45	62	83	34	21b	1
No treatment		—	—	—	—	—	37c	0

°Sown June 6; foliage sprays applied July 28 at 60 psi in 19 gal. H_2O/A; side dressings of 10 per cent granular material chiseled into the soil 6.5 inches deep and 5 inches from the plants on July 6 and irrigated the following day.

†Active ingredients in pounds per acre.

‡Numbers in parentheses are days after treatment.

§Average number of mites from all counts during the test period. Values are estimates of the number of mites in a circular area ½-inch in diameter (0.1936 sq. in.).

‖Values followed by the same letter do not differ significantly (P = <0.05) Duncan's multiple range test.

TABLE 32

DATA FROM A TEST OF GRANULAR SIDE DRESSING APPLIED TO TWO SOYBEAN VARIETIES, DAVIS, 1967°

Treatment	Application rate†	Per cent reduction of live mites‡				Number of mites§‖	Yield‖
		variety Chippewa					*lb. per acre*
		(14)	(21)	(28)	(35)		
Thimet® (phorate)	2	74	78	85	76	6a	305bc
Temik®	2	81	86	86	85	4a	446a
No treatment		—	—	—	—	38b	249c
		variety A-100					
		(14)	(21)	(28)	(35)		
Thimet® (phorate)	2	66	73	77	75	7a	312bc
Temik®	2	72	88	87	88	4a	352a
No treatment		—	—	—	—	27b	291c

°Sown June 12; side dressing of 10 per cent granular material chiseled into the soil 6.5 inches deep, 7 inches from the plants on July 17 and irrigated the following day.

†Active ingredient in pounds per acre.

‡Numbers in parentheses are days after treatment.

§Average number of mites from all counts during the test period. Values are estimates of the number of mites in a circular area ½-inch in diameter (9.1936 sq. in.).

‖Values followed by the same letter do not differ significantly (P = <0.05) Duncan's multiple range test.

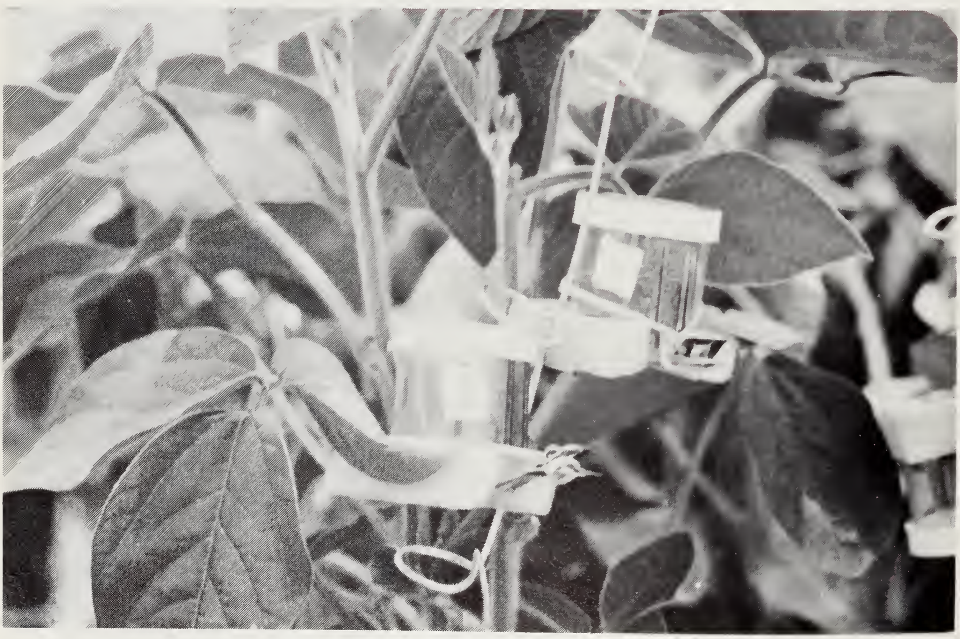
proved or registered for use on soybeans, and cannot be recommended until chemical registration and labeling are obtained and federal tolerances and registration are established.

Mite numbers versus damage. Comparisons of mite counts and damage are difficult because of variability in counts from one leaflet to another and from one area to another of the same leaflet. It is also complicated by migration. Nevertheless, these experiments indicate that counts above 5 in a circle ½ inch in diameter will lead to yellowing of the leaf and loss of

Severe spider mite damage, foliage loss, and poor pod set are shown in the soybean check plot in the foreground of this photograph.

yield. Above a count of 25, leaflets turn brown and dry up. Untreated plots show severe defoliation, and seedpod development is severely decreased.

The search for mite-resistant varieties. Different soybean plants and varieties show obvious differences in tolerance to mites under field conditions. Tolerance



Plastic cages 1-inch high and 1-inch in diameter mounted on underside of leaflets. One female was introduced into each cage (see text).

appears to be associated in part with stage of development, with later varieties appearing more tolerant in a nursery with early varieties, but becoming susceptible as they develop further. Even a uniform planting of a single variety will show variations in degree of susceptibility, apparently associated with microclimate. Hence, apparent variations in susceptibility under field conditions must be interpreted with great care.

Several varieties showing tolerance under field conditions were selected for greenhouse tests. A single female two-spotted mite was placed in a small plastic cage mounted on the underside of a soybean leaflet. The mites were transferred carefully to the leaflet surface on a one-to-three-bristled camel's-hair brush. The 1-inch plastic cages, cemented to a bent hair clip so they could be clamped tightly to a leaflet, had a soft foam backing to reduce leaflet injury. The plastic caps were removable for the introduction of mites. A hole drilled in the caps and covered with a very close-meshed cloth provided aeration. There were 10 replications for each variety. Table 33 gives results of a test of 10 varieties.

A 2-week mite developmental period proved most effective in measuring varietal differences in resistance. No variety showed complete resistance, but mite development was arrested on varieties P.I. 88,492, P.I. 70,212, P.I. 157,409, and Guelph.

Table 34 summarizes results from 14 greenhouse tests. Most of the varieties given a poor rating after 2 weeks are omitted from the table. B-106 (P.I. 88,492) and B-107 (UC-228) were the only varieties showing good to excellent mite tolerance. Both had 81 per cent fewer mites than the susceptible check variety, Chippewa.

Varietal field tests in 1968 at Davis verified the tolerance exhibited by B-107. Seed yield was not altered by phorate treatment of the tolerant variety B-107 with phorate at planting time and again as a side-dressing in the seedling stage. This is further proof that this variety arrests mite development and damage sufficiently to keep mite numbers below an economic threshold.

The 1969 varietal field planting at Davis resulted in excellent plant growth, and the very hot summer promoted high mite development, especially of the Pacific mite. This species made up about 90 per cent of the mite population present, and differences in damage among varieties were readily apparent. Mite counts (table 35) indicated that the varieties B-106 and B-107 reduced mite development the most. A new selection, M-59-213, showed good mite reduction. There was apparently no correlation between seed yield and mite tolerance among the lines tested.

Table 36 shows results from 1969 greenhouse tests on 10 separate soybean plantings. B-106 and B-107 were superior in reduction of mite development. These two varieties are still the most tolerant to spider mites. The selections UC-1022 and WI-4-221 exhibited fair to good mite tolerance, while CM-1 was good in one test.

Table 37 shows results from the 1970 greenhouse tests on seven separate plantings of seven soybean selections. These ex-

TABLE 33
AVERAGE NUMBER OF SPIDER MITES ON SEVERAL SOYBEAN VARIETIES, 2 WEEKS AFTER INTRODUCTION OF A SINGLE FEMALE INTO SMALL LEAFLET CAGES, DAVIS, 1967

Variety or plant introduction	Number of mites and date female was introduced		
	5/26/67	6/9/67	6/22/67
P.I. 88,492	11	5	16
P.I. 70,212	11	13	13
Chippewa	—	12	22
P.I. 84,976	16	11	22
P.I. 85,437	27	14	22
P.I. 157,409	10	7	9
P.I. 80,470	28	11	14
P.I. 86,449	19	15	21
Guelph	8	5	9
P.I. 68,494	10	9	43

TABLE 34

SOYBEAN VARIETAL DIFFERENCES IN NUMBER OF LIVE SPIDER MITES FROM A SINGLE CAGED FEMALE; INCUBATION TIME 2 WEEKS, DAVIS, 1968

Variety*	Number of tests per variety	Live adult and nymphal mites per cage	
		Average number	Per cent of Chippewa†
B-106 (P.I. 88,492)	3	7	19
B-107 (UC-228)	3	7	19
UC-208	1	10	28
Guelph	3	11	30
P.I. 157,409	4	12	32
UC-219	4	12	32
P.I. 85,437	1	12	32
UC-229	3	13	35
UC-218	2	13	36
UC-3,273	3	14	37
P.I. 70,212	3	14	39
UC-209	3	14	39
UC-220	2	16	44
Wayne	4	26	69
Chippewa	14	37	100

*All selections except named varieties were from materials originally supplied by Dr. R. L. Bernard. U.S. Regional Soybean Laboratory, Urbana, Illinois.

†The largest number of live mites developed on Chippewa, and this variety was used as the susceptible check variety.

TABLE 35

SOYBEAN VARIETAL DIFFERENCES IN NUMBER OF LIVE SPIDER MITES AT TWO DIFFERENT DATES IN FIELD EXPERIMENTS, DAVIS, 1969

Variety	Live adult and nymphal mites*†		Per cent of Chippewa‡		Average yield of seed
	8/20	9/9	8/20	9/9	*ounces per 100 feet of row*
B-106	6a	7a	24	11	9.2
B-107	5a	20b	20	30	10.2
M59-213	6a	24b	23	37	14.6
Hark	6a	49c	23	74	8.4
Amsoy	8a	51c	32	77	12.3
CM 31	10a	–	40	–	14.5
C1477	12ab	–	47	–	6.7
M55-130	14ab	–	55	–	21.0
Merit	14ab	–	56	–	15.8
Portage	18ab	–	69	–	17.2
Chippewa	26b	66d	100	100	6.0

*Average number of mites from five counts per variety. Values are estimates of the number of mites in an ½-inch in diameter (0.1936 sq. in.).

†Values followed by the same letter do not differ significantly (P = <0.05) Duncan's multiple range test.

‡The largest number of live mites developed on Chippewa, and this variety was used as the susceptible check variety.

tensive tests confirmed that the selections W-14-221, M-59-213, and CM-1, did indeed give superior reduction in mite development. The reductions were from 88 to 96 per cent, and along with B-106 and B-107 indicate their potential as breeding materials for future host plant resistance to spider mites.

Insects

The most damaging insect pest observed on soybeans is the western yellow-striped armyworm, *Prodenia praefica* Grote. These larvae are primarily foliage feeders, eating such prodigious amounts that plants are sometimes defoliated. Population densities can build up to damaging levels very sud-

Table 36
SOYBEAN VARIETAL DIFFERENCES IN NUMBER OF LIVE SPIDER MITES FROM A SINGLE CAGED FEMALE. INCUBATION TIME 2 WEEKS, DAVIS, 1969

Variety	Number of tests run	Average number of developed nymphs*	Per cent of Chippewa†
Chippewa	10	27	100
B-106	7	4	15
B-107	7	4	17
CM-1	1	7	27
UC-1022	6	7	28
WI-4-221	2	7	28
UC-1164	5	10	37
Dac 85	2	15	58
B-48	3	16	62
UC-208	1	17	62
UC-1021	2	17	65
B-25	3	17	65
B-23	3	18	69
UC-1244	3	21	77
UC-1498	3	26	97

*Average number of mites from all counts during the test period. Values are estimates of the number of mites in a area ½-inch in diameter (0.1936 sq. in.).

‡The largest number of mites developed on Chippewa, and this variety was used as the susceptible check variet

Table 37
SOYBEAN VARIETAL DIFFERENCES IN NUMBER OF LIVE SPIDER MITES FROM A SINGLE CAGED FEMALE; INCUBATION TIME 2 WEEKS, DAVIS, 1970

Variety*	Nymphs		Adults and Nymphs	
	Average number†	Per cent of Chippewa‡	Average number†	Per cent of Chippewa‡
CM-1	1	4	3	7
B-106	2	8	5	12
W-14-221	2	8	5	12
B-107	3	12	7	15
M-59-213	3	10	7	15
U.C.-1022	14	52	23	50
Chippewa	27	100	45	100

*Each variety was tested 7 times at different dates.

†Average number of mites from all counts during the test period. Values are estimates of the number of mites in an area ½-inch in diameter (0.1936 sq. in.).

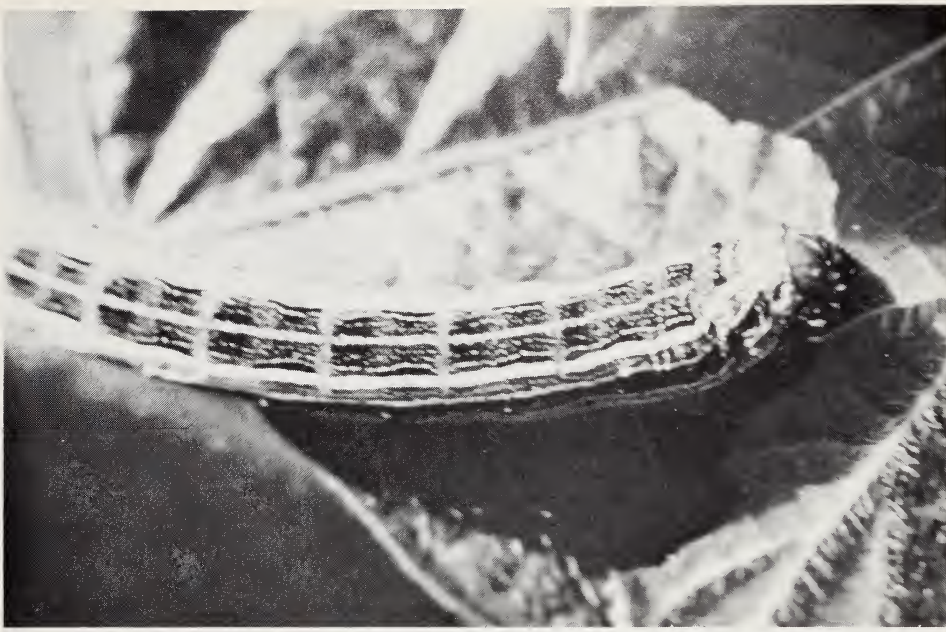
‡The largest number of mites developed on Chippewa, and this variety was used as the susceptible check variety.

denly in mid- to late-summer in some localities. Chemical control will occasionally be necessary.

The salt-marsh caterpillar, *Estigmene acrea* (Drury) can occasionally cause severe plant damage. It is also a foliage feeder. Other soybean leaf feeders are: the variegated cutworm *Peridroma saucia* (Hübner); the alfalfa looper *Autographa californica* Speyer; the alfalfa caterpillar *Colias eurytheme* Boisduval; and the beet armyworm *Spodoptera exigua* (Hübner). They have appeared sporadically and have caused minor damage.

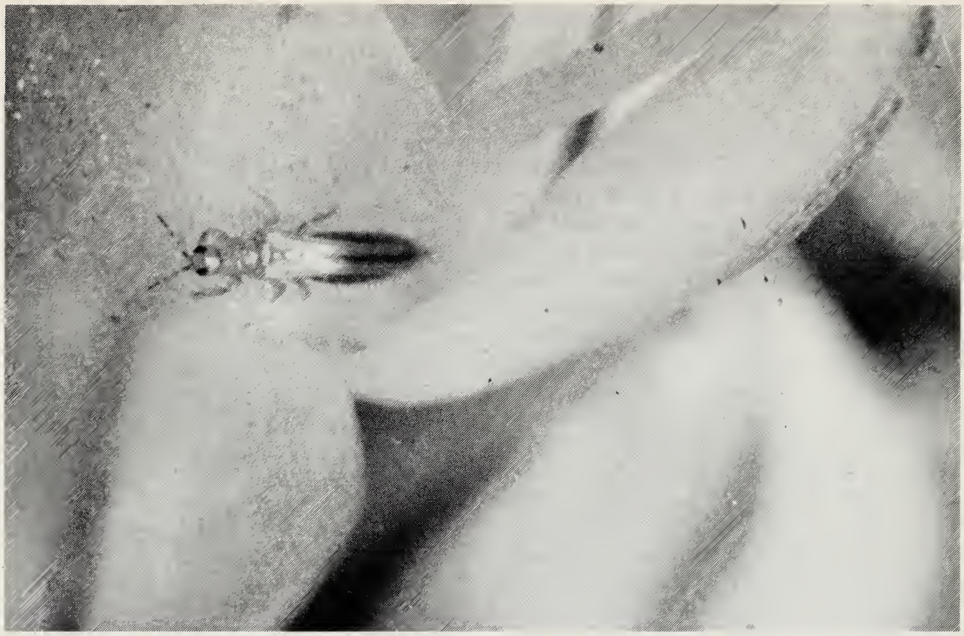
Western flower thrips, *Frankliniella occidentalis* (Pergande) have caused damage to young seedlings in early summer. However, they do not appear to damage flowers or reduce pod set.

Also found on soybean plants, though not in damaging numbers, are the consperse stink bug, *Euschistus conspersus* Uhler, other stink bug species, the lygus bug *Lygus hesperus* Knight, and the differential grasshopper *Melanoplus differentialis* (Thomas). Aphids have not been observed on soybeans, and the seed-corn maggot has caused no damage.



Western yellow-striped armyworm, Prodenia praefica **Grote.**

Salt-marsh caterpillar, Estigeme acrea **(Drury).**



Western flower thrips, *Frankliniella occidentalis* **(Pergande).**

Lygus bug, *Lygus hesperus* **Knight. Female adult at left, male adult on right.**

DISEASES

D. H. Hall

Soybeans are attacked by many organisms that can cause diseases, but diseases that may occur on the crop in California are not known because plantings here are mainly experimental. No limiting disease has appeared in any of the California tests and therefore we can only speculate as to which diseases might become important. The dispersal and survival of the pathogens involved in diseases in other areas are generally known, as are the environmental factors that favor various diseases, and consequently we can list the diseases most likely to attack soybeans in California. Since many soybean pathogens are associated with wet weather, they will probably not be major problems under the arid conditions that prevail for most of the growing season in this state.

This section briefly describes the diseases of soybean most likely to be encountered. Revisions can be expected as more experience is gained with the crop.

Diseases caused by bacteria

There are four bacterial diseases of soybean in the U. S., but none is likely to become serious in California because lack of rainfall during the growing season is not conducive to spread or infection by these pathogens. These diseases could possibly occur where the crop is irrigated by overhead sprinklers, thus creating an artificial rainfall condition. Two of them, bacterial blight and bacterial pustule, being seedborne are likely to be introduced into California on contaminated seed.

Bacterial blight. Symptoms of bacterial blight, which is incited by *Pseudomonas glycinea* Coerper appear first as watersoaked angular spots on leaves. The spots turn yellow and then brown as the tissue dies. Several spots may run together, and the dead tissue in the larger spots often drops out.

Bacterial pustule. Bacterial pustule caused by *Xanthomonas phaseoli* (E. F. Sm.) Dows var. *sojense* (Hedges) Star & Burkh. has similar symptoms, but the spots are yellowish-green with reddish-brown centers. Both diseases may result in tattered-looking leaves as dead tissue falls out.

Diseases caused by fungi

Most fungus pathogens that attack aerial portions of soybean plants are favored by wet weather and will probably never become established in California. Seed-borne fungi cause brown spot (*Septoria glycines,* Hemmi), downy mildew (*Peronospora manshurica* [Naum] Syd. ex Gäum), and frog-eye leaf spot (*Cercospora sojina* Hara). These will undoubtedly be introduced into the state but, lacking a favorable environment, are not likely to cause concern to growers.

Powdery mildew. Powdery mildew is caused by *Erysiphe polygoni* DC. (More recently a second powdery mildew fungus, *Mycrosphaera diffusa* G. W. Clint & Pk., has also been found infecting soybean.) The disease does not appear to be adapted to prolonged survival in the field in the present U.S. soybean-producing areas. Since powdery mildews are common on many crops in California, however, the disease could become a serious problem if soybeans are planted extensively.

Powdery mildew can be recognized by small colonies of gray-to-white fungus growth on the upper leaf surface. These colonies may coalesce and cover the entire surface, giving infected leaves the appearance of being covered with a white powder. Severely affected leaves die and drop from the plant.

Phytophthora rot. Phytophthora rot is caused by *Phytophthora megasperma* Dreschs. var. *sojae* A. A. Hildeb. Since many Phytophthora root rot diseases occur on other crops in California, this disease could likely become a problem. The fungus can infect the plant at any stage of development. It may cause pre-emergence and post-emergence damping-off, or reduction in vigor, or death of plants throughout the growing season similar to Phytophthora root diseases on other crops. The fungus causes a soft watery root rot

in the seedling stage, and rapid death follows. On older plants the disease is characterized by yellowing and wilting of leaves, often with brown lesions on the stem. The lesion may extend several inches both above and below the ground.

Phytophthora rot is found more often in poorly drained areas of fields and on fine-textured soils. Control requires use of resistant varieties and careful management to avoid ponding of water or soil water saturation.

Pythium rot. Pythium rot will probably occur in California since the causal organisms, *Pythium ultimum* Trow. and *P. debaryanum* Hesse., are common in cultivated soils. These fungi cause seed rot and damping-off of seedlings and may cause root and stem lesions on older plants. *P. debaryanum* causes stem tissue to appear watersoaked at first but dies rapidly, forming long sunken areas that may extend several inches above the soil; wilting and death of the plant follow. The disease is favored by cool, moist conditions. As the fungi that cause the disease are common, there is little that a grower can do to prevent the disease on older plants, although an approved seed treatment should provide protection against damping-off. A similar disease occurs on dry beans and blackeyes in California but has never been a major problem on those crops.

Rhizoctonia rot. *Rhizoctonia solani* Kuhn another fungus found in most cultivated soils, is common in California and causes severe disease problems on a number of crop plants. It may cause damping-off of soybean seedlings and a basal rot of stems on older plants. Reddish-brown lesions are formed in the cortical tissues of the belowground portion of the stem. The lesions often run together and girdle the plant, causing death.

Charcoal rot. Charcoal rot is caused by *Macrophomina phaseoli* (Maub.) Ashley. This fungus is common in California on corn, sorghum, and beans and is found occasionally on other crop plants. It attacks its host plants during hot weather, usually following severe water stress. The tissues of roots and stems are invaded by the fungus, which forms small black sclerotia. When the diseased tissue is peeled back, the exposed area is grayish-black (hence the name 'charcoal rot'). The disease will most likely be sporadic in occurrence and be associated with irrigating at irregular intervals.

Sclerotial (or southern) blight. Sclerotial blight, caused by the fungus *Sclerotium rolfsii* Sacc., is common to many areas of California and therefore can be expected on soybeans. It is most serious on sugar beets but also attacks many other commercial crop plants.

During hot weather the fungus causes a rot, near and below the soil line, that results in death of the plant. The disease resembles charcoal rot in some respects but can be differentiated by the development of fans of white fungus growth on the stem and in the adjacent soil and by the distinctive sclerotia of the fungus. The sclerotia, which are spheres about 1 to 2 mm in diameter, are white at first but become tan to dark brown as they mature.

The best control is rotation with nonsusceptible crops.

Stem rot. Stem rot is caused by *Sclerotinia sclerotiorum* (Lib.) d By. an organism found in many soils of California. As with the two diseases just mentioned, plant stems are attacked near the soil line. When the rot first appears it is soft and watery: affected tissue is often covered with white cottony growths that soon change to large, black, irregularly shaped sclerotia. Often these bodies may be formed in the stem. This disease is favored by cool, moist weather and is more likely to appear late in the growing season.

Diseases caused by viruses

Soybean mosaic. Soybean mosaic occurs to some extent in all soybean-producing areas of the United States. Infected plants are stunted, and leaves are a deeper green and narrower than leaves from healthy plants. The leaf margins turn down, and tissue along the main veins is puckered. Symptoms tend to be masked during hot weather. Infected plants have distorted pods, producing fewer seeds than healthy plants and seeds tend to show mottling of color in the seed coat.

The virus is spread from plant to plant by several species of aphids. Soybean mosaic virus is seed-borne, but per cent of

transmission varies with the variety (it may be as high as 100 per cent for very susceptible varieties). Transmission through the seed makes introduction of the disease into California very probable.

Yellow mosaic. The virus causing yellow mosaic of soybean is the yellow bean mosaic virus, common in dry-bean crops in California. It is transmitted by aphids. Symptoms are a yellow mottling on younger leaves, developing into necrotic spots as the leaves mature. The disease is seldom a serious problem, even though widely distributed in the Midwest.

Bud blight. Bud blight of soybean is caused by the tobacco ringspot virus. Symptoms vary with the stage of plant development. With infection before flowering the growing point turns brown, recurves, and becomes dry and brittle. Plants are dwarfed and produce very little seed. With infection during flowering, plants produce small undeveloped pods. Plants infected after flowering produce poorly filled pods that have conspicuous blotches. The virus is transmitted to the seed only if it infects before flowering.

The tobacco ringspot virus has been found in California but is not common. This virus could be introduced in infected seed, and since the nematode species that transmits the virus is present this disease could conceivably become a problem.

HARVEST AND STORAGE

J. R. Goss, M. D. Miller, R. T. Edwards

Field experiments at Davis and the U.C. West Side Field Station, and recent results obtained by California farmers clearly show that soybeans are easily combine-harvested because mature seeds are of a size and smoothness that make them readily rubbed out of the mature pods and easily separated from dry straw. Improper production practices and negligent combine-harvester operations can result in soybean field losses as high as 20 to 30 per cent (Bowers, 1967). The national average is about 10 per cent, divided as follows:

Source	Per cent
Shattered	4.0
Left on stems and lodged	2.0
Left on stubble	2.0
Left by machine	2.0
Total loss	10.0

Annual losses of potential income in this way are about 162 pounds of beans per acre, valued on the farm at about $8.60 (1972 prices). Management tools are available to reduce this loss.

The following is a summary of California soybean-harvesting experience, coupled with findings in the U. S. soybean-growing areas.

When to harvest

As soybeans reach physiological maturity most of the leaves naturally turn yellow and drop to the ground (even without frost) and seed moisture is rapidly lost, decreasing from about 60 per cent to 15 per cent or less in 1 to 2 weeks (Carter and Hartwig, 1963). Atmospheric conditions at the time have a great influence on the rate of water loss. For example, prolonged rain or fog will slow the drying.

Seed moisture at harvest. Although soybeans can be combined when the beans have reached 15 per cent moisture, harvest efficiency is best when seed moisture is down to 12 to 14 per cent. For safe storage, beans harvested with higher moisture must be dried down to about 13 per cent or lower by aeration (with atmospheric or heated air). Delaying harvest until moisture is 6 to 8 per cent will result in excessive pod and seed-shatter losses by the header. When fields have dried excessively, night harvesting helps reduce shatter losses.

Chemical maturation. Since soybeans ma-

ture in the fall, growers are anxious about possible rain damage and therefore would like to use chemical foliage sprays to speed harvest readiness. Unfortunately, USDA experimental results in the soybean-growing areas have shown that defoliating soybeans 3 weeks prior to normal yellow leaf drop reduced yield by 30 per cent and speeded the harvest date by only 3 days (Carter and Hartwig, 1963). University of Illinois studies showed that any chemical treatment applied early enough to accelerate seed drying appreciably reduced yields. In the soybean-growing areas, the chemical defoliants presently available have been generally most useful in desiccating green weeds in weedy fields to improve havest conditions.

Soybean defoliation tests with varieties Chippewa and Hawkeye were conducted at Davis for 2 years, but no materials or methods used hastened harvest readiness to a practical extent. In one experiment a commercially registered defoliant containing 40 per cent sodium chlorate and 58 per cent sodium metaborate was applied at 15 pounds per acre as a spray on October 15, when Chippewa had most of its leaves but some pods were ripe, and when Hawkeye had all of its leaves and the pods were green (table 38). The defoliant did not dry up the Chippewa beans or stems any faster than in untreated controls, though it gave some improvement in drying time in the later-maturing Hawkeye variety. No yield data were collected.

In 1957, four desiccating materials were tested on Chippewa soybeans at Davis. The chemical sprays were applied on September 21 to facilitate early-October harvest. All chemicals began to desiccate and defoliate the plants within 7 to 10 days. Several days of heavy rain in the second week of October interrupted the experiment. All materials tended to reduce yields, whether desiccating systemically or by contact (table 39).

In summary, soybean defoliation with currently available chemicals has the same results in California as in other soybean-growing states. None has been effective in speeding harvest date without reducing yield. Some have been useful in desiccating weeds prior to harvest. Growers planning to try chemical desiccation of weeds should make certain the compound is registered for the purpose, and follow the label instructions carefully.

Direct-combining soybeans

For best combine-harvesting, cultural practices should provide: (1) evenly spaced rows 20 to 30 inches apart; (2) 6 to 9 plants per foot of row; (3) level seed beds free of large clods and with gently sloping shoulders; (4) soybean plants with pods beginning more than 4 inches above the soil; and (5) no green weeds. Once the beans are below 14 per cent moisture, the harvester operator may have many opportunities to adjust his machine and methods as field conditions change.

Causes of combine losses. Harvester losses come from: (1) improper header adjustment; (2) improper cylinder adjustment; and (3) separation losses. Most current adapted varieties do not naturally shatter excessively before maturity.

A major source of bean loss is a poorly operated header. Cutting too high causes

Table 38
EFFECT OF DESICCANT SPRAY ON MOISTURE CONTENT OF SEEDS AND STEMS OF TWO SOYBEAN VARIETIES, DAVIS

Date	Days after treatment	Per cent moisture							
		Chippewa				Hawkeye			
		Seed		Stems		Seed		Stems	
		Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
10-15	0	53.1	53.1	72.7	72.7	66.4	66.4	72.1	72.1
10-20	5	36.1	35.1	72.9	71.2	—	—	—	—
10-26	11	25.3	18.1	69.6	71.6	55.3	51.9	70.5	71.5
11-2	18	8.3	11.4	68.2	67.9	36.6	29.0	70.2	65.5
11-11	27	—	—	—	—	16.8	11.7	63.2	60.8

TABLE 39
EFFECTS OF FOUR DEFOLIANT CHEMICALS ON CHIPPEWA SOYBEANS, DAVIS

Chemical used	Amount of material			Harvest readiness dates*	Yield
	Chemical	H_2O	Oil		
	gallons per acre				*lb. per acre*
Dow General® dinotro phenol	¼	20	10	10/15	1788
Endothal®†	2	15	—	10/15	1422
Magron®	¾	15	—	10/17	1764
E-Z Off®†	2	20	—	10/17	1878
Control	—	—	—	10/20	2016
LSD_{05}					340

*14 per cent moisture or less.
†6.3 per cent by weight of disodium 3.6-endoxohexahydrophthalate.
‡60 per cent magnesium chlorate hexahydrate + non-boron fire-suppressant.

losses from cutting through pods with beans falling to the ground, and from unharvested pods left in the field on standing stubble. To prevent this, the cutter bar must generally be operated no higher than 3 to 6 inches from the soil surface (using a header height gauge will help reduce losses from this source). When the crop is lodged, pickup guard attachments for the the cutter bar will help recover beans which would otherwise go unharvested.

Another source of potential heavy field loss is excessive header-reel speed. When reel speed is too high the dry pods and beans are batted from the plants and lost. Peripheral reel speed should be adjusted to travel about 25 per cent faster than the forward ground speed of the combine. Peripheral speed in feet per minute = 3.1416 times reel shaft speed in revolutions per minute times reel diameter in feet. Forward speed in miles per hour (mph) can be converted to forward speed in feet per minute by multiplying mph by 88. The center of the reel should be adjusted to be about 1 foot ahead of the sickle bar, so that the reel gathers in and brushes the plants toward the combine without batting the beans on to the ground. Although combines operating in soybeans may move forward twice as fast as would be the case if they were harvesting cereals, if the forward movement of the combine is too fast the bean plants are pushed forward, with the cutter bar cutting them higher up as they lean forward. Excessive amounts of beans are thus left uncut in the field, and shatter losses are excessive. University of Illinois research has shown that the faster a combine travels, the higher it must be set to avoid the risk of running the header into the ground. Table 40 shows the results from tests in Illinois (Bowers, 1967). Combine cylinder speed and screen and fan adjustments are important in minimizing broken and ground-up beans and loss of beans out of the rear of the harvester. The Operator's Manual for the combine will provide useful adjustment guidelines as a starting point. If the peripheral cylinder speed is correct but there are shattered beans in the grain tank, the trouble may be the result of too many beans riding over the clean grain (lower) screen and being cracked as they recirculate through the

TABLE 40
EFFECT OF COMBINE SPEED ON FIELD LOSS OF SOYBEANS
UNIVERSITY OF ILLINOIS (BOWERS 1967)

Combine speed	Stubble height	Loss
mi. per hour	*in.*	*lb. per acre*
2.5	6.4	210
3.2	7.3	282
5.0	9.3	348

cylinder. A heavy load of threshed beans in the return can usually be decreased by opening the clean grain screen. If the beans are very dry (below 10 per cent moisture), cylinder speeds should be 1500 feet per minute or less.

Improper cleaning of the threshed sample may be due to insufficient air on the shoe screens, overthreshing, weedy conditions, or improper engine speed. Cylinder speed and concaves should be adjusted to rub all of the beans out of the pods with minimum damage to the beans and minimum break-up of the straw. The amount of air on the shoe screens will vary from two-thirds to the maximum possible. The lower screen should normally be 3/8-inch open, and the top screen 1/2- to 5/8-inch open. High loss of threshed beans over the straw walkers or rack is most frequently the result of overloading the combine.

Harvest experiments. In combine field tests at Davis with variety Chippewa, cylinder speeds of 1778 and 1490 feet per minute were tested, with cylinder clearance 5/8 inch in front and 3/8 inch in back. Since only four tests were conducted, no significance is necessarily associated with the fact that two of the three tests conducted at a harvest rate of about 2 acres per hour gave a large increase in cutter bar losses. With these machine adjustments used, harvested beans were of planting-seed quality.

Recommendations for combine operations

Begin harvest operation as soon as possible after the beans in the field average 14 per cent moisture or less. Do not wait until they are less than 10 per cent.

To minimize unharvested pods, operate the combine header as close to the soil surface as possible. Use a header-gauge attachment.

Header reel peripheral speed should be about 25 per cent greater than forward ground speed of the combine. Harvest slowly for minimum field loss.

Presently available chemical desiccants have not proved practical for accelerating bean maturity, but are effective in solving a green weed problem prior to soybean harvest. If used, follow manufacturer's label instructions.

Cylinder speeds ranging from 1500 to 1800 feet per minute have given good results in California experiments for low-moisture beans.

COMBINE SOYBEAN HARVEST TEST, DAVIS, 1957

Harvester Factor	Test Number* 119	120	121	122
Harvest rate (acres per hour)	1.0	2.07	2.07	1.93
Cylinder speed (ft. per minute)†	1778	1778	1490	1490
Cylinder clearance (front/back, inches)	5/8–3/8	5/8–3/8	5/8–3/8	5/8–3/8
Cutter bar loss (lb. per acre)	45	157	106	46
Clean seed harvested (lb. per acre)	2825	2525	1568	2500
Straw walker loss (lb. per acre)	15	7	9	4
Shoe loss (lb. per acre)	77	68	52	49
Total free seed loss (rear combine, lb. per acre)	10	16	13	13
Total unthreshed seed loss (rear combine, lb. per acre)	82	59	48	40
Total harvesting loss (lb. per acre)	137	232	167	99
Total harvesting loss (per cent gross yield)	4.6	8.4	9.0	3.8
Estimate pre-harvest loss (lb. per acre)	15	14	8	13
Gross yields (lb. per acre)	2962	2757	1535	2599
Condition harvested seed:				
US Grade	2	2	1	1
Mechanical damage (per cent through 8/64" r. h. screen)	0.04	0.08	0.07	0.1
Split and broken seed (per cent on 8/64" r. h. screen)	3.48	3.17	3.20	3.99
Total mechanical damage (per cent)	3.52	3.25	3.27	4.09

* Test 119 was in 6-inch drilled rows. Tests 120, 121, and 122 were with 30-inch drilled rows. Lifter guards were used in Tests 119 and 120. Seed moisture at harvest was 10%.

† Cylinder speed in ft./min = 3.1416 × cylinder diameter in ft. × rpm.

Cylinder concave clearances of 5/8 inch in front and 3/8 inch in back have resulted in a minimum of harvester damage to low-moisture beans.

As the harvest days proceed and plants become drier, make combine adjustments to keep bean crackage minimized. If necessary, harvest at night.

Seed storage. For safe storage after harvest, soybeans should be placed in clean, dry bins or flat storage and maintained no higher than 13 per cent moisture (Holman and Carter, 1952). If beans coming in from the field are mixed with green trash they should be cleaned before being binned.

If harvested soybeans have more than 14 per cent moisture, they can be dried by forced air (atmospheric or heated). Maximum air temperature for drying soybeans should not exceed 110° F.

SOYBEANS FOR FORAGE AND GREEN MANURE

M. D. Miller, R. T. Edwards, W. A. Williams

Soybeans may be used in California as a summer-grown crop for hay or silage production or for green-manure purposes. Good soybean hay has a feeding value about equal to other high-quality legume hay, although the coarse stems which make up 10 to 15 per cent of the soybean hay may be refused by some animals. The coarse-stem problem can be largely overcome by using an increased seeding rate, by proper date of planting, and by well-timed harvesting (Morse and Carter, 1952).

Experience in the Midwest has shown that soybeans can be made into an excellent silage in combination with corn. There, a combination comprised of about 2 or 3 parts corn to 1 part soybeans makes a well-balanced silage that keeps well and is readily eaten. Because of the interest in silage feeding in California, various possible crop combinations were tested in both Sacramento and San Joaquin Valley counties.

Forage varieties. Although varieties grown for bean production may be used, the special forage or "hay types" generally yield the best quality forage. These usually have fine stems and small, dark-colored seed. Tests have shown, however, that bean types adapted for California conditions when drilled at 100 to 180 pounds per acre in close drill rows will equal the special forage varieties in quantity and quality of forage produced.

Time to cut. For hay or silage purposes soybeans may be cut from the time the pods begin to form until the pods begin to mature, but harvest should begin well before the leaves begin to fall. Hay mowed at the earlier stage will have a protein content of 16 to 18 per cent. Cut at the later stage, the protein content will probably be below 15 per cent, though total hay yield per acre likely will be somewhat higher.

Because soybean leaves shatter readily when dry, and because the stems dry slowly relative to the leaves, special harvest precautions are necessary to produce good quality hay.

A good method of curing soybean hay is to leave it in the swath for 1 or 2 days, then rake it into small windrows. If drying conditions are poor, the small windrows may need turning once or twice before baling. Using swathers or mowers equipped with roller-crusher or crimping attachments will hasten the curing or drying process because crushed soybean stems lose moisture more rapidly than intact stems.

Hay experiments

Forage as well as oil bean variety tests were conducted at Davis and in several counties during 1955 to 1960. Plantings made in mid-May, 1955, at Davis gave a yield of about 2½ tons per acre of dry matter containing about 18 per cent protein when harvested in late July or 11 weeks af-

Table 41

HAY YIELDS AND ANALYSES FROM SOYBEANS SOWN AT TWO DATES, DAVIS, 1955

Date sown	Date cut	Variety	Stage	Height (inches)	Leaf loss (per cent)	Dry matter (per cent)	Dry matter (pounds per acre)	Protein (per cent)
May 14	July 27	Harosoy	Late bloom	44	0	19.0	4910	17.0
May 14	July 27	Clark	Early bloom	36	0	17.6	4750	18.9
May 14	Aug. 10	Harosoy	Early pod	55	5	22.1	6690	16.0
May 14	Aug. 10	Clark	Late bloom	46	15	20.0	6820	17.4
July 2	Sept. 8	Chippewa	Early pod	44	15	18.2	5120	18.7
July 2	Sept. 8	Harosoy	Late bloom	50	15	18.2	4900	17.8
July 2	Sept. 8	Hawkeye	Late bloom	48	20	18.4	4970	19.9
July 2	Sept. 8	Perry	Early bloom	44	25	15.2	4760	19.4
July 2	Sept. 8	Lee	Vegetative	48	15	17.4	5050	18.9

ter seeding (table 41). Plots harvested at 13 weeks yielded about 3½ tons per acre, but the protein content had dropped to about 17 per cent. At Hamilton City in Glenn County hay yields of the better varieties were almost 3 tons per acre when harvested about 16 weeks after planting (table 42). When cut about 10 weeks after planting, about 2½ tons of hay per acre were obtained at Davis from a planting made July 2. The better varieties sown on June 29 at Hamilton City gave a yield of less than 2 tons per acre when harvested 14 weeks after planting. Varieties did not appear much different in hay yields at Davis, but late maturing varieties were much better at Hamilton City.

In 1956 soybean hay experiments, comparisons included the special soybean forage varieties Kingwa and Virginia and three yellow-seeded oil-bean varieties. The test at Davis was sown in 6-inch drill rows on May 27, and was harvested on September 5. Chippewa yielded 8,625 pounds per acre of dry hay and had 18.3 per cent protein (table 43). The high protein content was a consequence of its mature stage of development.

Another forage test was sown at the U.S. Cotton Research Station, Shafter. The same five varieties used at Davis were sown at two dates, May 7 and June 15. Row spacing in these tests was 40 inches. The varieties were harvested when the pods and beans were well developed. All varieties had between 14 and 17 per cent protein (table 44). The yield of Kingwa was over 7 tons and for Lee over 8 tons of dry hay per acre. It was noted in this test as well as at Davis that Lee had very coarse stems and was difficult to harvest. Kingwa and Virginia, the forage type soybeans, had fine stems and lodged, but were not difficult to harvest. Similar results have been obtained in other tests at various locations in California in other years.

Row spacing, seeding rate and harvest date influence soybean hay yield as well as quality. The protein content of stems, pods and leaves determines the quality of the

Table 42

HAY YIELDS FROM SOYBEANS SOWN AT TWO DATES, HAMILTON CITY, 1955

Date sown	Date cut	Variety	Dry matter (pounds per acre)
May 9	August 30	Chippewa	4414
May 9	August 30	Blackhawk	3213
May 9	August 30	Lincoln	5880
May 9	August 30	Clark	5621
May 9	August 30	Lee	5333
June 29	October 8	Chippewa	2113
June 29	October 8	Blackhawk	1702
June 29	October 8	Lincoln	2350
June 29	October 8	Clark	4444
June 29	October 8	Lee	3584

TABLE 43
HAY YIELDS AND ANALYSES FROM SOYBEANS CUT AT DIFFERENT DEVELOPMENTAL STAGES, DAVIS, 1956 (SOWN MAY 27)

Variety	Stage*	Dry matter (pounds per acre)	Protein (per cent)
Chippewa	Nearly mature	8625	18.3
Lee	Late bloom	8211	16.1
Clark	Developed pod	7829	15.2
Kingwa	Early pod	7684	11.4
Virginia	Early pod	7595	11.1
Average		7989	14.1

*All varieties harvested on September 5.

hay. Stems have the lowest protein content (approximately 12 to 14 per cent), leaves have a protein content of 19 to 20 per cent, and the protein content of the pods varies from a low approximating that of the stems to a high of 25 to 27 per cent depending on the stage of development. As the pods become more mature there is a loss of leaves. The ideal harvest time occurs before there is any appreciable loss of leaves but after the beans and pods have started to mature.

Silage experiments

In general, soybeans alone are not recommended for silage making. This is because the green soybean plants will produce a rather bitter ensilage with a strong, disagreeable odor unless the material is wilted to 60 to 65 per cent moisture before being chopped and tightly packed into the silo. The addition of a carbohydrate additive such as chopped corn in the ratio of about 2 or 3 parts corn plant to 1 part soybeans usually will produce a well-balanced silage that keeps well and is readily eaten by livestock (Morse and Carter, 1952). The question is in what combination to grow soybeans for ensiling.

In a corn and soybeans silage test conducted in Tulare County in 1956, we found that soybeans grown alone could not be harvested green with a field chopper but had to be mowed and dried before chopping. Alternating rows of corn and soybeans grew well, but again there was the difficulty of harvesting soybeans alone. Soybeans planted within the row of corn appeared the most successful method of mixing the two crops for silage; they grew well together and presented no difficulty in harvesting. The seeding rate when interplanting should be 14 pounds per acre of corn and 35 pounds per acre of soybeans. Table 45 gives data from this test.

Sudan and soybeans have been used in the Midwest as an ensiling combination, but correct row spacings, seeding rates, and dates of planting must be used to achieve desirable results. An experiment at Davis in 1957 illustrates some of the difficulties. On May 22 two varieties of soybeans (Clark and Kingwa) were seeded in 30-inch rows at 35 pounds per acre. Sixteen days later, Piper sudan was drilled in 6-inch rows crossways of the soybean rows, using four different seeding rates:

TABLE 44
HAY YIELDS AND ANALYSES FROM SOYBEANS SOWN AT TWO DATES. U.S. COTTON RESEARCH STATION, SHAFTER, 1956

Variety	Sown May 7			Sown June 15		
	Date cut	Dry matter	Protein	Date cut	Dry matter	Protein
		lb. per acre	*per cent*		*lb. per acre*	*per cent*
Lee	Sept. 18	16,120	14.9	Not harvested	—	—
Kingwa	Aug. 29	14,560	15.4	Sept. 28	8,320	16.3
Virginia	Aug. 29	9,880	14.1	Sept. 28	9,360	15.9
Clark	Aug. 13	8,840	15.5	Sept. 28	9,360	17.3
Average		12,350	15.0		9,013	16.5

TABLE 45
DATA FROM A CORN-SOYBEAN SILAGE TEST IN TULARE COUNTY, 1956

Treatment	Seeding rate		Dry matter
	Corn	Soybeans	
		lb. per acre	
Soybeans alone (variety Lee)	—	90	4,823
Corn-soybeans alternating	18	100	9,380
Corn-soybeans interplanted	12	20	9,986
Corn alone (Pioneer 302)	20	—	10,400

10, 20, 30 and 40 pounds of sudan seed per acre.

A month later, the sudan and the soybeans were nearly equal in height. Before harvest, the sudan at the two higher seeding rates almost completely shaded out the soybeans. Sudan at the lower seeding rates did not compete so severely but the soybeans were weakened and succumbed to spider mites. Effective control of the mites on the soybeans was difficult because of the tall growth of the sudan. This experiment shows that local experience with methods of planting this combination is important for good results.

Soybeans for green manure

Adapted soybean varieties may be used as a summer cover or green manure crop in California. For best results, soybeans should not be allowed to become too mature before being turned under. USDA tests indicate that the highest nitrogen content and approximately the highest yield of green and dry matter are obtained when soybeans are in full bloom (Morse and Carter, 1952). Where a summer grown soybean green manure crop was turned under between each potato crop in a Kern County experiment, the potato marketability never dropped below 99 per cent in 7 successive crop years, whereas in other treatments there was a highly significant increase in unmarketable scabby potatoes (due to *Streptomyces scabies* [Oswald *et al.*, 1956]). The effect on scab of growing soybeans to maturity and turning under the dry straw was not determined.

SUMMARY AND CONCLUSIONS

B. H. Beard

Soybeans, originally introduced into the U.S. from the Orient about the turn of the century is an extremely important crop in many areas. Even though the cattle and poultry industries, and other consumers in California use 600,000 to 700,000 tons of soybeans or soybean products annually at a freight cost of approximately $22 million, the crop has not become established in California. A small acreage of soybeans is grown for hay, silage, forage or as green manure but even for these uses the crop is of minor importance in California.

Production costs for soybeans are similar to other cultivated row crops. Cost estimates vary from $80 to over $100 per acre with our high land values and irrigation costs. If the farmer receives 3¼ to 4½ cents per pound of beans, a yield of 3,000 to 4,000 pounds per acre is required for a reasonable margin of profit. With this production level 400,000 to 500,000 acres could be devoted to the crop just to meet California needs. Unfortunately, yields over 2,500 pounds per acre have been rare in California even though many tests have been conducted throughout the state. Growing soybeans as a second crop after harvesting a cereal crop, or after early harvested sugar beets, potatoes, or vegetables, is a method of reducing production costs by 15 to 25 per cent. Even so it appears that a sustained research program is needed to develop varieties that will give

maximum yields under irrigation in a hot dry climate. In California, low relative humidity and soil with a high pH appear to be the environmental conditions that show the most extreme departure from conditions found in soybean production areas.

Soybean production does not require any specialized equipment, and a farmer growing other row crops will have the necessary machinery (or it will be available from custom operators).

Deep friable soils with good drainage and aeration characteristics, but with high water intake and holding capacity, are ideal for optimum growth. Soil salinity should not be over 5 mmhos per centimeter, and although small amounts of boron are required either in soil or irrigation water anything over 0.5 ppm will cause a necrosis of leaves that can lead to leaf or plant death (depending on concentration). Soils with less than 40 pounds of phosphorus per acre may require fertilization with approximately 50 pounds of P_2O_5 per acre. Potassium is generally not limiting in California soils, and soybeans will not require nitrogen fertilizer application if properly nodulated.

Soybeans can be planted anytime from early April until July 1st with only minor differences in yield. Seedbed preparation should be similar to that used for other irrigated row crops in the district but double-cropping procedures may be more profitable (as discussed on pages 18 to 20). Only high-quality seed should be used and seed purchase well in advance will be necessary because seed is not regularly available in California. Seeding rates vary with row spacing (55 pounds per acre for 40-inch rows, 65 pounds per acre for 30-inch rows, and 75 pounds per acre for 20-inch rows) but about ten seeds per foot of row, irrespective of row spacing is about right. The seeds should be placed into firm moist soil to about 1 inch and not more than 2 inches below the surface. The soil over the seed should be pressed but not packed around the seed and planters should be designed to leave the surface soil loose over the seed. If high temperatures and low humidity prevail during planting time, or if planted as a second crop, an irrigation as soon as possible but not more than 2 or 3 days after sowing will lower soil temperatures and increase the stand.

The first time the crop is sown in a field soybean seed should always be inoculated with the soybean type of *Rhizobium* bacteria. It is usually advisable to inoculate again if more than a year has passed since the last time soybeans were grown or if the soil was allowed to become completely dry between crops. Inoculation may be done in a farm building or in a shady spot in the field by sprinkling 3/4 to 1 pint of water on 60 pounds of seed in a wash tub; the recommended amount of inoculum is then added and stirred by hand until all the seed is almost black with the inoculum. The inoculated seed should be kept in a shady spot and covered with a damp cloth. It is best to place only small amounts of seed in the planter boxes and the inoculated seed should be sown immediately.

Selection of the proper variety for the location is very important. We have divided California into four areas based on the maturity of the varieties that should be grown. Be sure to get seed of a variety with proper maturity characteristics for the location. South of the Tehachapi Mountains maturity groups V, VI and VII should be grown; in southern San Joaquin Valley maturity groups IV or V; in the central San Joaquin Valley maturity groups II and III are best; and in the southern Sacramento Valley maturity groups 0 or I have given the highest yields.

Weed control is essential for profitable production of soybeans, and as with other crops a good all-around program is needed. A combination of herbicides and cultivation will probably be required. Consult your Farm Advisor for the latest information on herbicides that are registered for use on soybeans, and follow directions on the label.

Spider mites are always a potential threat to soybean production throughout California. Research has indicated that chemical control is possible but is generally too expensive. Some soybean resistance or tolerance to spider mites has been found but has not been incorporated into adapted varieties. Consult your Farm Advisor for methods of control for spider mites or insects.

Soybean diseases have not been important limiting factors in any experimental planting in California. If large acreages were grown regularly, disease might become important.

Proper irrigation practices are an important consideration in soybean production but unless the field has extremely poor drainage the plants will suffer as much from too little water as from too much. Depending on soil characteristics, the crop will require from 20 to 30 inches of water during the growing season. The number of irrigations may vary from two to twelve and will be similar to the needs of other crops grown at the same time.

Soybeans should be combine harvested as soon as the beans in the field average 14 per cent moisture. Do not wait because beans will begin to shatter from the pods at less than 8 per cent moisture. Combine cylinder speeds should be from 1500 to 1800 feet per minute with concave clearances 5/8 inch in front and 3/8 inch in the back. The combine header should be kept as close to the ground as possible and the use of a header-gauge attachment is recommended. The header reel speed should be about 25 per cent greater than the forward speed of the combine. Soybeans must be clean and have 14 per cent or less moisture for proper storage.

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To simplify the information, it is sometimes necessary to use trade names of products or equipment. No endorsement of named products is intended nor is criticism implied of similar products not mentioned.

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